SLOPE STABILITY INVESTIGATIONS BETWEEN KOHIMA AND MAO WITH SPECIAL REFERENCE TO NH-39

BY

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Submitted

In partial fulfillment of the requirement of the Degree of
Doctor of Philosophy in Geology
of Nagaland University

NAGALAND UNIVERSITY

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DECLARATION

I, Ms Meniele Khalo, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University/Institute.

This is being submitted to the Nagaland University for the Degree of Doctor of Philosophy in Geology.

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CERTIFICATE

The thesis presented by Ms Meniele Khalo, M.Sc., bearing Registration No. 347/2008 (6th December 2007) embodies the results of investigations carried out by her under my supervision and guidance.

I certify that this work has not been presented for any degree elsewhere and that the candidate has fulfilled all conditions laid down by the University.

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Sd/-

(MENIELE KHALO)

PREFACE

National Highway No.39 is the connecting link between the two states, Nagaland and Manipur. It is the sole means of surface transportation and the life line connecting the two states. Due to frequent landslides, particularly during monsoon season, traffic along this highway is often disrupted varying from one to two weeks, sometimes even a month. In view of this, the present investigation has been taken up to map the landslide occurrences, their causes and governing factors.

This study is carried out following the recommendations of the Bureau of Indian Standardthat has been duly modified suiting thestudy area. Extensive field surveys have been conducted to map geological structures, litho-units, groundwater condition, and land use/land cover. Satellite imagery is used to identify structural features and landslide incidences are marked with a hand-held GPS.

The present study is an attempt to generate the Landslide Hazard Zonation (LHZ) map using Geographical Information Systems. It includes preparation of various thematic layers including slope morphometry, relative relief, lithology, structure, ground water condition, landuse/land cover using IRS LISS-III satellite data and topographical maps so as to make a risk assessment of some weak zones along the highway to provide mitigation measures.

A LHZ map of 1:4000 scale is generated based on the results of the above mentioned parameters.Landslide incidences are overlaid on LHZ to study their relationships and validatedthe results.Rock and Slope Mass Rating of slope material in the slide areas have been estimated and kinematic analysis performed to understand the probable mode of failure. Data generated have been interpreted in terms of failure type and potential failure. Suitable recommendations have been proposed for such areas.

Geotechnical analyses were conducted to identify geotechnical parameters of soils in the unstable areas. Inorder to understand the firmness of the soils, consistency limits of the soils in the slide area were evaluated.Direct Shear Test is conducted inorder to determine the shear strength of soil.

It is hoped that the concerned agencies will use the LHZ map as a basiswhile planning for any future developmental activities by way of adopting recommendations provided to enhance slope stability and to reduce risk.

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CHAPTER 1

INTRODUCTION

The term landslides comprise an extensive series of ground movement which includes rock falls, shallow debris flow and deep failure of slopes. One key geomorphic progression where hill slopes develop is also because of Landslide action. This character signifies places where the consistent strength of rock and soil masses that make up a slope are conquered by the force of gravity which is continually inducing the materials down slope. In all the places on a hill slope it can be considered as a constant tug-of-war involving the driving force of gravity against resisting force. Natural processes and human modifications of slopes both can change this balance in support of gravity. The force of the slope material is compressed because of changes related to weathering, seepage erosion; groundwater changes etc., whereas on the other hand stresses on the slope can be enhanced by external factors such as loading of slopes, steepening of slopes because of excavations, etc. Several of the ancient landslide scarps and also their deposits were masked by vegetation and therefore have been transformed by natural processes and also by human interventions. These areas stay firm for a long phase until the slope has been disturbed by natural processes like intense rainfall and human involvement regarding construction activity.

Landslides have great impact on society and the environment, both short-term and long-term. Loss of life and properties are some short-term effects while the long-term effects comprises of landscape alteration and loss of cultivable land, shifting and also relocation of populations and establishments thereby causing massive economic losses and displacing habitation.

It is estimated that about 4 percent of the total annual deaths world-wide are related to natural hazards. And landslide is one of the major elements of natural disasters. Approximately a number of people killed by landslides per year per 100 sq km area is more than one. The highest number of lives lost to a single landslide event occurred in the Kansu Province of China in 1920. In 1970, another well known landslide incident happened on the slopes of Mt. Huascaran, Peru, killing more than 18,000 people.

Some of the notably high landslide risk zones of recent studies are Colombia, Tajikistan, China, Nepal and also India.

Throughout the monsoons and year after year of intense rain, our country always experiences landslides. Different regions are affected in a varied manner because of characteristic physiographic, geologic, climatologic and tectonic conditions. This has affected the hilly regions of our country to a total of about 15 percent. Around the globe different types of landslide incidences occur and more so in the geodynamically active area of the Himalayan and Arakan-Yoma regions. The Himalayan mountain ranges and hilly tracts of the North Eastern region where Nagaland and Manipur lies, is ornamented with rugged hills of variable heights. The mountain ranges striking NE-SW run almost parallel to each other. The region is impregnated with deep gorges, sharp ridges and narrow elongated valleys along which swift flowing streams make the terrain very susceptible to landsliding.

1.1 OVERVIEW OF THE STUDY AREA

1.1.1 Location of the area

Northeast India lying at the south juncture of the Himalayan Arc with the Burmese Arc on the east is one of the most seismically active regions of the world. The mountain ranges of the northeast for the most part, represent a young mountainous terrain that is highly dissected and relatively immature. Here, landslides are annually recurring phenomena with the onset of the monsoon every year. Nagaland and Manipur, lying in the northeastern corner of India, are mostly rugged mountainous terrains. Nagaland represents a narrow strip of mountainous country with Manipur to its south. Nagaland, with an area of 16,579 sq km, lies approximately between 25°.6'N and 27°.4'N latitudes and between 93°.25'E and 95°.15'E longitudes. Manipur occupies an area of 22,347 sq km and lies between 23°.83'N and 25.68°N latitudes and 93°.03'E and 94°.78' E longitudes. It lies in the Survey of India (SoI) topographic map no. 83 K/2. It starts from the south of Kohima town and terminates at Mao, the northern-most township of Manipur bordering Nagaland (Fig. 1.1). It lies between 25°38'57.4''N latitudes and 94°06'25.6''E longitudes to 25°30'31.2''N latitudes and 94°08'07.8''E longitudes.

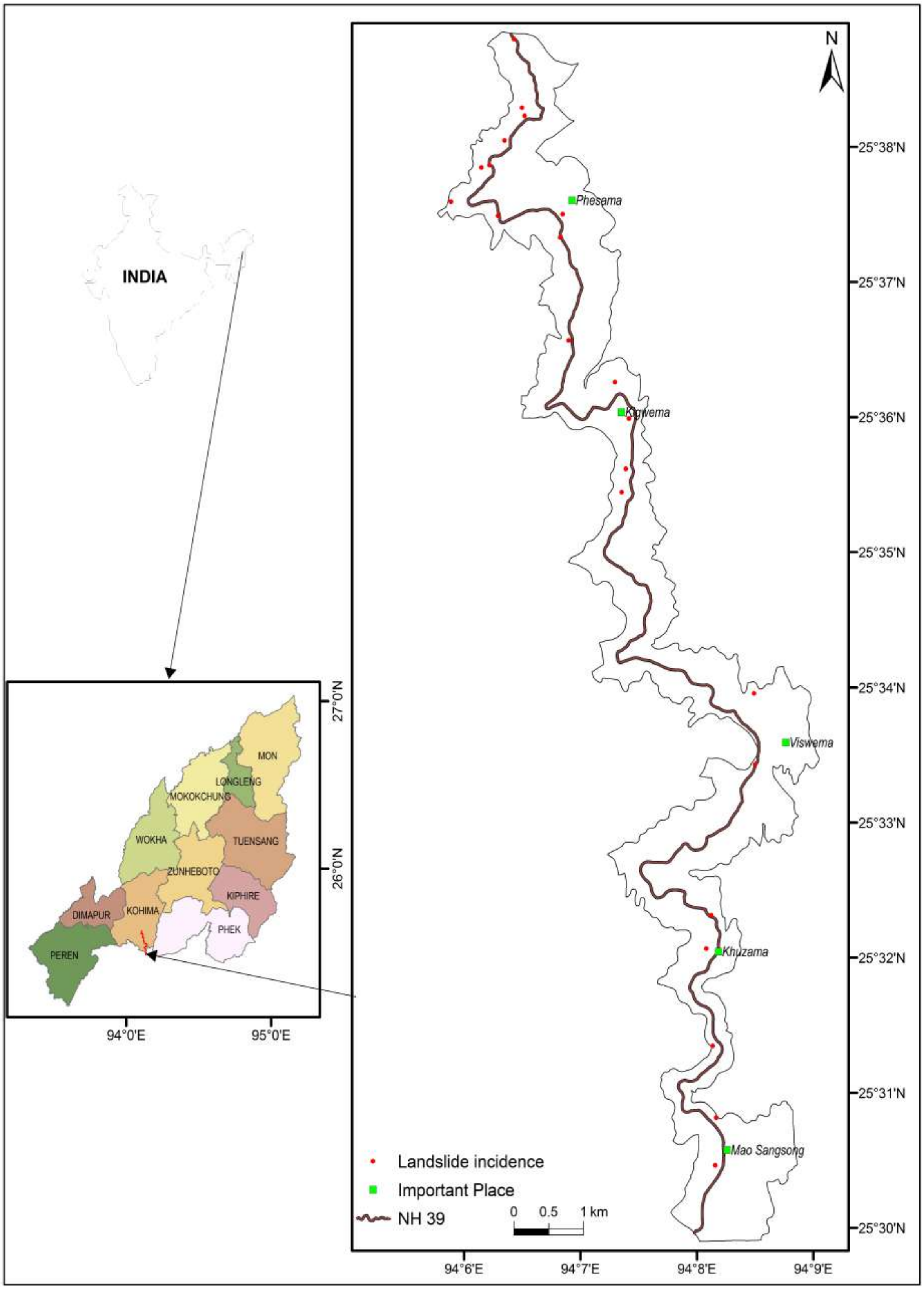


Fig 1.1 Location Map

The National Highway (NH) 39 is the lifeline of the people of the study area. As far as national highways go, this highway is quite short in length for its modest 436 km. NH 39 originates from Numaligarh, a refinery town in Assam's Golaghat district, which lies about 250 km east of the state capital Guwahati. The highway then enters Dimapur, the commercial town in Nagaland. It then continues into Kohima the state capital, 74 km away, from where it enters into Manipur state through Mao town, which is about 32 km from Kohima, to end in the town of Moreh at the Indo-Myanmar border. It takes about 19 hours of travel from Numaligarh to Moreh. This NH 39 that is Manipur's lifeline is often affected by landslides, which is a great source of distress.Due to a limited number of roadways in the region and poor alternate routes, travellers and essential commodities are stranded on this highway for many hours during such natural calamities. People often have to cross the troubled spots on foot with at risk of their lives. In both the states of Nagaland and Manipur, the Border Roads' Organization and state Public Works' Department are constantly engaged during the monsoon, in clearing of debris to keep the highway motorable, by working round the clock. A major handicap is that no major scientific investigations have been carried out along the section except for some case studies.This NH 39 is soon to be an international route under the Look East Policy of the Government of India. A thorough knowledge of the physiography, geology and impact of human activity on nature is of prime importance in understanding the causes of landslides and suggesting control measures. The safety factor should be calculated for all types of soils before any developmental works are executed. This study is designed to prepare a landslide hazard zonation (LHZ) map of the study area and geotechnical analyses of soils of two major landslides. This will lead to awareness of the impact of landslide hazards and to prepare society for suitable action to reduce both risks and costs associated with this hazard.

1.1.2 Accessibility

Both Nagaland and Manipur have a good network of roads that connect to the rest of the country. The NH 39 connects Dimapur to Imphal, through Kohima. The railhead is located at Dimapur. Dimapur in Nagaland has a small airport with one flight every day. Imphal in Manipur is better connected by air with several flights every day.

1.1.3 Geomorphology

This study area covers a very rugged topography of highly dissected denudational hills, steep cliffs, narrow valleys and deep gorges. The average altitude of the area is about 1444 m above mean sea level. A great part of this area is clad with evergreen forests. The hill ranges trend more or less NE-SW and are nearly parallel to each other. Large part of the lower hills and lowlands has become barren due to terrace cultivation.

1.1.4 Climate

The area enjoys a sub-tropical climate. Temperatures go up to 30°C in summer. January is the coldest month of the year where temperature falls to 4°C or less. The humidity is moderately high during summer.

The area receives abundant rainfall during the monsoon, with an annual average of 2500 mm. Storms commonly occur during the monsoon in this region.

1.1.5 Drainage

The highway is commonly cut across by high order streams. Some of these streams dry up during the winter months. As the streams are in their youthful stage, they cut deep gorges along their paths. DzuchaRu, MoziRu, KehoRu, ChokwiDzü, PhileRu, Pijelru are some of the streams in the study area (Fig.1.2).

1.1.6 Flora and fauna

Thick evergreen to semi-evergreen, virgin forests cover the uninhabited parts of the study area. A large variety of indigenous and non-indigenous species of plants like wild apple, bansam, wild cherry, titachap, pine, gamari, alder, hazel nut, chestnut, walnut, oak and the famous and tallest rhododendron arboretum etc. are available. Varieties of bamboo, plantain and orchids are also found in this area. Shrubs of various varieties like barberry, blushing viburnum and raspberry are abundant.

The area is also rich in fauna. The mammals include wild cats, guinea pig, porcupine, mongoose, etc. The reptiles are represented by a number of species of poisonous and non- poisonous snakes and lizards. Insects, bees, snails, frogs, caterpillars, worms of various kinds are also common. A variety of fish are found in the streams and numerous species of birds like pigeon, sparrow, etc, are noted in the forest.

Fig 1.2 Digital Elevation Model

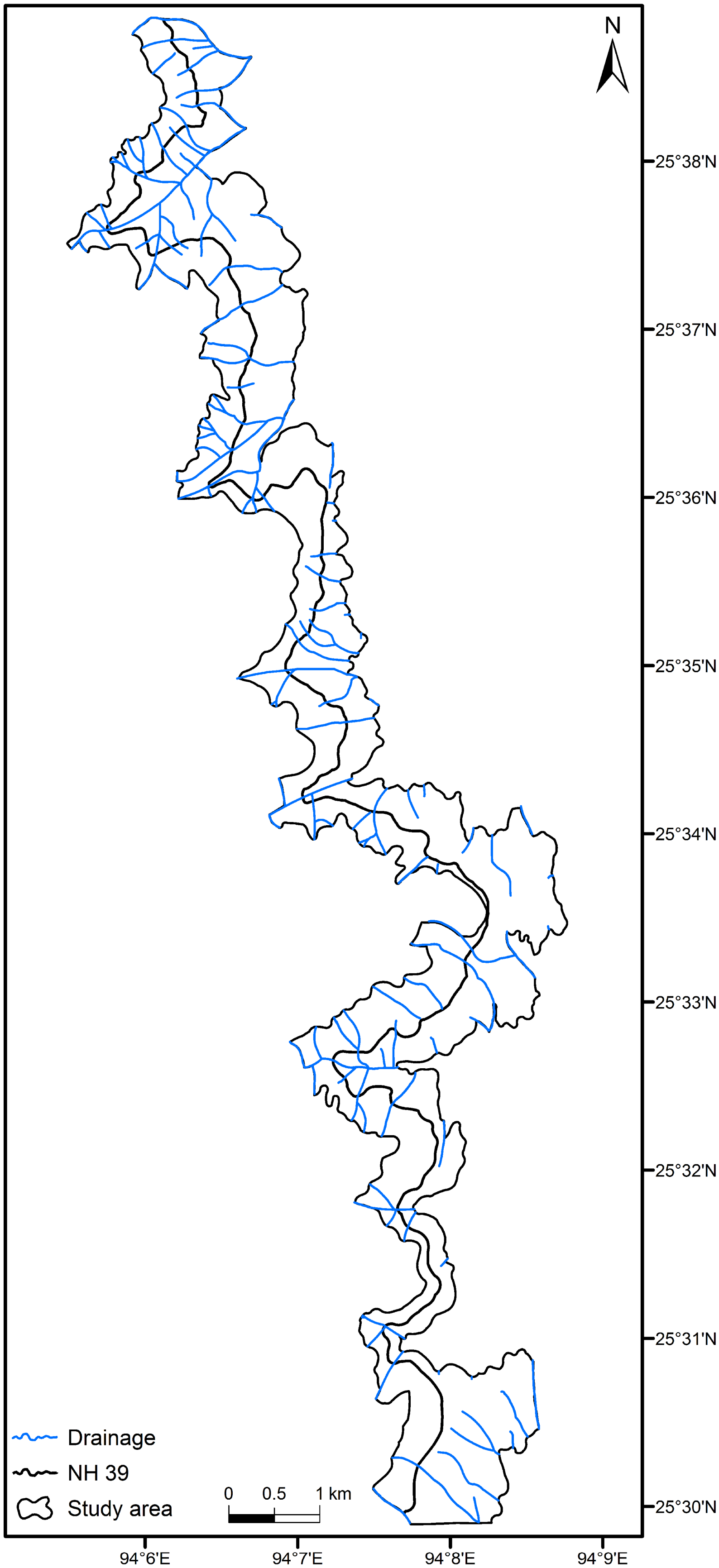


Fig 1.3 Drainage Map

Table: 1.1 Rainfall Data of Kohima town (Source: Department of Soil and Water conservation, Kohima).

Month	2004 (mm)	2005 (mm)	2006 (mm)	2007 (mm)	2008 (mm)	2009 (mm)	2010 (mm)	2011 (mm)	2012 (mm)	2013 (mm)	2014 (mm)
January	2.9	7.6	0.00	0.00	43.80	0.00	1.40	11.7	32.70	0.00	0.00
February	3.5	33.3	39.20	70.30	5.00	10.60	8.20	35.4	15.20	0.00	16.8
March	10.6	101.2	8.60	16.10	54.10	24.60	56.90	47.6	49.20	45.20	31.80
April	217	55.4	80.70	146.5	35.00	32.10	60.80	88.7	81.50	115.40	77.60
May	174.5	171.1	170.90	343.5	170.70	138.40	119.50	159.2	130.80	332.50	145.50
June	209.2	263.8	298.70	241.5	398.40	205.70	347.10	333.8	218.80	298.20	139.00
July	547.9	175.6	206.40	314.5	453.10	277.20	53.76	371.8	295.70	350.90	332.40
August	237.6	346.1	139.50	416.5	393.50	388.20	464.30	364	258.70	268.50	350.60
September	285.2	255.7	283.50	182.3	320	216.80	226.50	250.1	123.60	226.30	231.40
October	161	147.7	83.70	19.14	12.57	129.40	162	126	124.30	112.10	--
November	15.3	4.5	26.20	79.40	0.00	0.00	2.10	35.2	40.20	0.00	--
December	0.2	8.3	1.00	1.80	0.00	0.00	21.20	7.8	0.00	0.00	--
Annual Rainfall	1864.9	1570.3	1338.40	1831.54	1886.17	1423.00	1523.76	1831.3	1370.70	1749.10	1325.10

1.1.7 Soil and outcrops

The soil cover in the area, including rock and soil debris is variable in thickness, ranging from 2 m to more than 12 m. Soil exposures are commonly reddish brown to light brown in color. In some vegetated locations they are dark gray, soft and loamy. The area is rich in outcrops. These outcrops are a result of erosion by streams, gravity, faulting, hill-slope cutting for widening of roads and other developmental activities, etc. However, it is not possible to trace the continuity of structures and rocks for large distances due to the soil cover, vegetation and human settlements.

1.1.8 Lithology

This rugged terrain is made up of the Disang and Barail groups of rocks which are exposed intermittently along the highway (Fig 1.3). At Kohima, the highway passes through Disang shales. The Disang is made up dominantly of shale with intercalations of siltstones and sandstones. The Barail is made up dominantly of sandstone with thin beds of papery shale. The highway runs, for the most part, through Disang rocks.

1.1.9 Structure

This part of the region is tectonically very disturbed. As a consequence, the rocks are highly folded, faulted, fractured, jointed and sheared. The tectonic disturbance is associated to the subduction of the Indian Plate beneath the Burma Plate, resulting in over-thrusting of the older formations over the younger ones. The older structure generally inhabits the eastern part of the state while younger structure lie towards the west (Ibotombi, 2000).

The study area is a part of the Kohima Synclinorium, the steep and upper reaches forming the western limb of the synclinorium. The Churachandpur-Mao Thrust is positioned along the south of the study area. Parallel and angular stream pattern align the study area where their courses were controlled by joints and fault planes. Faults of limited extent are eminent within the study area. Numerous lineaments are recognized on the Satellite imageries. Shear zones and areas of crushed rocks form the major sites of sinking and sliding. The rocks show 3 to 4 sets of joints. The shear zones are accountable for continuous subsidence of roads; predominantly during the monsoon. There are also indications of neotectonic activity. Proof for neotectonism is the existence of abundant black clays along fault planes (Directorate of Geology and Mining, Nagaland 2001). Where in such areas water is to be found even in the dry season.

1.1.10 Land use and land cover

Both on the uphill and downhill sides of the highway small patches of forests, fallow land, and cultivated tracts are prominent. These cultivated tracts comprise areas under terrace cultivation.

1.2 OBJECTIVES

The NH 39 is the lifeline for the inner districts of Nagaland and Manipur state. In view of the importance of this highway, the proposed work will lead to the generation of a LHZ map of the area and determine the causes of instability. Geotechnical analyses of two major active slides of the area will be carried out to determine their causes and understand their mechanism of failure. Appropriate mitigation measures will be provided for the slides as well as for the weak zones in the area. The following are the objectives for the present work.

1. To study the causes of instability which will include geoenvironmental parameters like slope, relative relief, lithology, structure, groundwater condition and land use / land cover.
2. To create a spatial database using Geographic Information Systems (GIS) and to construct thematic maps using SoI topographic map on 1:25000 scale, satellite imagery of IRS-1D (PAN+LISS III merged) and P6 (PAN) and information gathered in the field.
3. To assign values for each of the geo-environmental parameters and then consolidating them for determination of the total estimated hazard.
4. To construct a large-scale LHZ map for the area.
5. To determine the mechanical properties of rocks and soils in weak zones.
6. To suggest mitigation and preventive measures for such areas.

CHAPTER 2

GEOLOGY OF NAGALAND

2.1 GEOLOGICAL SETTING

Nagaland tectonic hills are part of the Arakan-Yoma ranges of Cretaceous-Tertiary age. The subduction of the Indian Plate beneath the Burma Plate began during the Cretaceous. Large negative isostatic anomalies to the east of Arakan-Yoma, high seismicity and depth of foci are evidences of continuing subduction (Nandy, 1976; Verma, 1985; Bhattacharjee, 1991). This susceptible region consists of high hills and deep valleys which forms an integral part of the northern extension of the Indo-Myanmar Range (IMR). The IMR is an arc-shaped tectonic belt that is convex towards the west. The IMR is divided longitudinally into three segments such as the Naga Hills, Chin Hills and Arakan-Yoma Hills (Brunnschweiler, 1974).

The state is dominantly made up of undulating hills and sharp crested ridges with narrow elongated valleys and steep gorges. The alluvial plain of Dimapur is a continuation of the Brahmaputra valley of Assam. The mountain ranges are high with peaks such as Saramati (3826m) along the Nagaland-Myanmar border.

Naga Hills

The northernmost segment of the IMR constitutes the Naga Hills, which trends approximately NE-SW. This segment is constituted primarily by the Naga-Patkai Hills of Nagaland and northern part of Manipur. Brunnschweiler (1974) classified this region into three major lithostratigraphic units, the Naga Metamorphic Complex, Naga Hills Flysch and the Upper Chindwin Molasse of the Chindwin Basin. Acharyya (1986) classified this section on the basis of geologic and tectonic setting into two distinct longitudinal belts, namely the Central Naga Hills Paleogene flysch and the Naga-Chin Hills ophiolite belt.

Chin Hills

The Chin Hills is positioned amid the Naga Hills on the north and Arakan-Yoma segment in the south. They are chiefly composed of flysch sediments with minor igneous and metamorphic rocks. On the south identified as Kanpetlet schist which belongs to a group of schistose rocks overthrusts the Lower Tertiary unmetamorphosed shales and sandstones with conglomeratic layers to the west. Brunnschweiler (1974) explained this fragment of the IMR without ophiolites but with exotics in the flysch sediments. Probably resulting to be the basis on which the two segments, the Naga Hills and Chin Hills were detached.

Arakan-Yoma Range

The Arakan- Yoma- Range lies to the south of the Chin Hills and encompasses low hills and covers the coastal areas of Myanmar. Though moderately less, Ophiolite rocks, are identified on the eastern side as small outcrops. The entire strike of the tectonic lineaments is NNW-SSE and the tectonic position of this segment is more or less than the other two segments.

2.2 STRATIGRAPHY

The NH 39 runs through a terrain of diverse features. The mountains trending NE-SW, are more or less, parallel to each other. Part of this terrain is made up of tough sedimentary rocks such as sandstone while others are made up of broken shales. This region is representative of major Cretaceous-Tertiary orogenic upheavals. The stratigraphy of Nagaland (Imchen et al., 2014) is given in Table 2.1.

Metamorphic Complex

Metamorphic complex is an isolated section of the Pre-Tertiary Burmese continental crust possibly of Pre-Mesozoic age and is a part of the eastern fringe of Nagaland (DGM, 1978). Metamorphic complex consist of a cover of meta-sediments which are primarily members of calc-psammopelitic sequences. Mica schist, granitoid gneiss and feldspathic metagreywacke with tectonic slices of ophiolite of variable dimensions form the main litho-units of the Naga Metamorphics. These occur as a klippe above a thrust plane dipping east and overlying the younger mélange zone. Whereby the formation is overlain by the Nimi Formation consisting of interbands of phyllite, quartzite, limestone and quartz-sericite schist.

Zepuhu Formation

This linear belt of Upper Cretaceous age that trends NE-SW, and is about 90 km in length and varies from 5 to 15 km in breadth. The Zepuhu formation representing the Ophiolite Complex of Nagaland lies between the Nimi Formation in the east and the Disang Group of rocks on the west and are distinguished by dismembered tectonic slices of serpentinite, cumulates and volcanics. They are often associated with pelagic sediments such as chert and limestone, found interbedded with the volcanic rocks. The Cherts are usually bedded and bear radiolarian. Fossil records in limestones indicate an Upper Cretaceous-Lower Eocene age.

Jopi / Phokphur Formation

The ophiolite suite of rocks is unconformably overlain by an open marine to paralic sedimentary cover which has been designated as the Phokphur Formation. These are essentially ophiolite-derived volcano-clastics. This formation comprises tuffaceous shale, sandstone, greywacke, grit and conglomerate and is considered equivalent to the Barail. Carbonaceous matter added with minor limestone is eminent in these rocks.

Disang Group

The Disang Group of rocks ranging in age from Upper Cretaceous to Eocene, is the oldest of the Tertiary in Nagaland. Made up of a thick sequence of shales intercalated with very fine grained, flaggy sandstone and siltstone have been categorised as a basal argillaceous and an upper arenaceous horizon or as Lower and Upper Disang formations respectively (Sinha et al., 1982).

The Disang shales are distinguished for their organic content which gives the shales their characteristic dark gray to black colour. Box-work and spheroidal weathering (Plate 2.1) are common and the presence of pyrite in the Disang indicates that they were deposited under reducing conditions. Studies indicate that these rocks belong to a deep basinal set-up (Imchen, et al., 2014) and were deposited in a marine environment, probably at great depths where anoxic conditions prevailed. At a later date these sediments were uplifted. Ultimately weathering and erosion of the overlying rocks has exposed the present area. The Disang represents a flysch facies, they are found over more than half the surface area of Nagaland. As it goes higher up the stratigraphic coloumn the volume of shales decreases and the presence of sandstone become more prominent. The Disang grade vertically and laterally into the

Barail Group of rocks where at numerous places reddish to brownish Disang are noted due to oxidation of pyrite. Ferruginous concretions and nodules are common features in red soils. Two main processes namely, air breakage and the dispersion of colloidal material brings about weathering of shale (Badger et al., 1956). Consequently, talus and scree form at the base of slopes and thick columns of soil are formed on slopes, rendering the Disang dominated areas vulnerable to various forms of slope failure, which includes landslides. Disang are splintery by nature having very low shearing strength. This splintery nature is practically due to the intersection of bedding and a prominent fracture cleavage (Soibam, 1998). Areas of steep slopes and thick overburden are sites for slope failure. A number of landslides are noted due to intensive weathering of shales together with jointing, faulting, etc. Most of the highway running over Disang is affected where shaly silts, silty shales and bedded siltstones are found. This extensive displacement in the rocks is the result of numerous faults and possibly thrusts.

This part of the region receives abundant rainfall and cloudburst is common. Taking all this factors into consideration and not forgetting the anthropogenic activity, it is but natural to see instability in the area. In Disang country a number of present day landslides have occurred in paleoslide zones reminding us of continued instability of the region.

Barail Group

The Barail, named after the Barail Range in the North Cachar Hills of Assam, is an arenaceous suite of flysch sediments. These rocks of Upper Eocene-Oligocene age, conformably overlie the Disang and comprise of thick sequences of sandstones intercalated with thin shale. They are found scattered all over Nagaland. The Barail may be divided in the south and southwest of Nagaland into three formations including Laisong, Jenam and Renji. In the northern intermediate hills of Nagaland they are recognized as Tikak Parbat, Baragolai and Naogaon formations.

The Barail exposed in the study area belong to the Laisong Formation where it conformably overlies the Upper Disang. They are made up of well-bedded quartzose-sandstones alternating with hard, sandy shale. The greywacke are weakened by two to three sets of joints at most places, commonly finely laminated, very tough and greyish in colour. Occasionally, massive sandstones with intercalations of carbonaceous shale and thin streaks of coal are noted. The Jenam is made up of massive sandstones with intercalations of shale, sandy shale and calcareous and iron stained shale. The youngest member, the Renji are essentially sandstones that are hard, massive, ferruginous and very thick bedded, with intercalations of minor shales. This formation has thick forest cover forming high peaks such as Japfü (3015 m) in southern Nagaland which lengthens along the southwest of Nagaland into Assam and south into Manipur. These rocks limited to the Schuppen belt along the western margin of Nagaland, are of marine to estuarine origin occasionally exposed as inliers due to strike faulting. Fossils and sedimentary structures are rare but structures such as ripple marks, load casts, flute marks and current bedding are noted.

In the north-eastern parts of Nagaland, the Naogaon Formation is extensively exposed as high ranges which are hard, grey, thin bedded and fine to medium grained and often intercalated with some shale and carbonaceous shale. Concretionary structures are also sporadically seen. Further towards the south the sandstones are thick and massive with thin shale partings. The Tikak Parbat and Baragolai formations are made up of sandstone, shale, carbonaceous shale and coal which include workable coal reserves. Towards the south these rocks branch out in northern Manipur.

Surma Group

The Surma are subdivided into the Bhuban and Boka Bil formations. The surmas are characterized by the presence of conglomerate which unconformably overlies the Barail. They consist of Lower Miocene molasse and alternations of well-bedded sandstones, shaly sandstones, mudstones, sandy shales and thin conglomerate. On the western margin almost along the entire length of Nagaland, the rocks are exposed in the form of a number of long narrow strips running along the schuppen belt which gradually thins out towards the north.

Tipam Group

The Tipam molasse belonging to Mio-Pliocene group unconformably overlies the Surma. Tipam Group includes the older Tipam Sandstone and the younger Girujan

Clay which are exposed along the western border of Nagaland in the schuppen belt as long, narrow strips due to strike faulting.

They include massive, highly friable with subordinate clay and shale where the sandstones are generally coarse grained, occasionally gritty and ferruginous. Due to presence of chlorite they are commonly green in colour but weather to different shades of brown. The argillaceous Girujan Clay Formation consisting of mottled clays, sandy clays and sandstones in subordinate amounts overlie the Tipam Sandstone. These clays are exposed in the schuppen belt and also along the western section of Nagaland. The formation encloses bluish-gray mottled clays with minor sandstones.

Namsang Beds

Lying unconformably over the Girujan Clay, the Namsang Beds of Mio-Pliocene age, belong to the Dupi Tila Group. They are confined to the schuppen belt and comprise of sandstone, pebbles of lignite, conglomerate, grit, mottled clay and lenticular seams of lignite.

Dihing Group

The Dihing Group of Plio-Pleistocene age unconformably overlies the Namsang Beds. They consist of an unconsolidated mass of Barail cobbles and pebbles mixed together in a matrix of clay and soft sand. The deposits are found as few patches in the schuppen belt.

Alluvium and High-level Terraces

Alluvium and high-level terraces are common features observed in many parts of Nagaland. High-level terraces are mainly boulder beds consisting of coarse sand, gravel and clay at a range of levels above the present rivers. The older alluvium is composed mainly of cobbles and boulders with considerable amounts of clay, silt and sand occupying the northeastern tract of the Naga-Patkai ranges. The newer alluvium covers the western border of Nagaland and is mainly composed of dark gray to black clay, silt and sand deposits and they occur as recent deposits of rivers and streams.

Table 2.1. Stratigraphy of Nagaland (after Imchen et al., 2014)

Age	Group	Litho-formations		
		Outer and Intermediate Hills		**Eastern Hills**
Recent - Pleistocene		Alluvium and high level terraces		
	Dihing	Boulder beds		
		--------Unconformity---------		
Mio-Pliocene	Dupi Tila	Namsang Beds		
		--------Unconformity---------		
Miocene	Tipam	Girujan Clay Tipam Sandstone		
	Surma	Upper Bhuban Lower Bhuban		
		--------Unconformity---------		
Oligocene	Barail	Renji	Tikak Parbat	<u>Jopi / Phokphur Formation</u> Tuffaceous shale, sandstone, greywacke, grit and conglomerate. Minor limestone and carbonaceous matter
		Jenam	Baragolai	
		Laisong	Naogaon	
Upper Cretaceous - Eocene	Disang	Upper		
		Lower		Shale/slate/phyllite with calcareous lenses in basal sections and invertebrate and plant fossils in upper sections with brine springs
		-------Base not seen-------		-------Fault/Thrust-------
Upper Jurassic - Upper Cretaceous	Ophiolite Complex			**Zepuhu Formation** Marine sediments (shale, phyllite, greywacke, iron-rich sediments, chert and limestone with radiolaria and coccoliths), volcanics (basalt, spilite, volcaniclastics), metabasics greenschist, glaucophane schist/ glaucophane-bearing metachert, eclogite), layered cumulate sequence (peridotite, pyroxenite, gabbroids, plagiogranite, anorthosite), and peridotite tectonite and serpentinite associated with deposits of podiform chromite and nickeliferous magnetite, minor Cu-Mo sulphides associated with late felsic intrusions and some dolerite dykes
				------Fault/Thrust-------
Pre-Mesozoic (?)	Naga Metamorphic Complex			**Nimi Formation** Weakly metamorphosed limestone, phyllite, quartzite and quartz-sericite schist **Naga Metamorphics** Mica schist, granitoid gneiss and feldspathic metagreywacke with tectonic slices of ophiolite in variable dimensions

2.3 MAJOR STRUCTURAL UNITS

Major structural features of Northeast India and Myanmar emerged as a result of collision of the India subcontinent with the Eurasian and Burma plates. Desikachar (1974) and Nandy (1976) have clarified the evolution of major features relating to a plate tectonic model. They justified that during the Mesozoic the Andaman-Arakan-Assam basin existed between the Burmese landmass and the Indian plate and had extended from 5° to 27° N latitudes. When Gondwanaland rifted the eastern margin of the Indian Peninsula was at latitude 50° S and got positioned in an E-W direction (Chatterjee and Hotton, 1986). Ever since the Cretaceous, the Indian plate has moved northward and the eastern continental passive margin rotated 20° in a clockwise direction until the Late Eocene when it collided with Eurasia (Gordon et al., 1990). This theory is supporteded by oceanic magnetic anomalies (McKenzie and Sclater, 1971) and palaeomagnetic studies of the Indian rocks (McElhinny, 1973). The considerable relationship between high seismicity, depth of foci and large negative isostatic anomalies to the east of the Arakan-Yoma suggests that the subduction process is still continuing (Verma, 1985).

Nagaland portrays part of the mobile morphotectonic unit of the Indian Plate that collided with Burma Plate (Bhattacharjee, 1991). These stresses are responsible for the major structural units of Nagaland where the major lineaments trends NE-SW and a NW-SE compression direction. Ultimately, all the structures like reverse faults and folds are parallel to the regional NE-SW trend. But some of the joints, Normal faults, and tensile fractures are parallel to the NW-SE compression direction. The crustal rocks of this mobile belt have gone through much compression which resulted to large-scale surface deformation. Subsequent to the three orogenic events of the rising Himalayas these section has undergone three deformational episodes F_1, F_2 and F_3. F_1 signifies an early Alpine-Himalayan incident. The surface rocks of Nagaland do not show signs of this orogenic movement. F_2 produced large NE-SW, low to moderately plunging asymmetric open folds and some major NE-SW thrust planes signifing a Late Alpine-Himalayan event. The F_3 Pliocene-Quaternary open folds trends NW-SE / WNW-ESE which are small and moderate to high plunging and partially asymmetrical. Roy and Kacker (1986) is of the opinion that F_2 and F_3 deformations are post-collisional features. Aier, et al., (2011a) suggest that neotectonic features in the region are a result of ongoing F_3 movements. Looking from the tectonic and structural point, Nagaland is geologically very complicated. Basing on morphotectonic elements, Nagaland can be longitudinally separated into three distinctive units, the "Schuppen Belt", the "Inner Fold Belt" and the "Ophiolite Complex" from west to east (Goswami, 1960; Mathur and Evans, 1964; DGM, 1978). All of these major structures have NE-SW trends.

Schuppen Belt

Schuppen Belt forms a very complex pattern and runs from the northwestern margin of Nagaland embracing eight to ten NE-SW trending overthrusts. Along the western margin of this belt, juxtaposing parts of the Tipam and Barail against the Sub-Recent to Recent alluvium, an en-echelon fault system known as the Naga Thrust is erratically exposed. This thrust is composed of a succession of six thrusts where the uppermost member is the persistent Disang Thrust, which occupies the southeast.

Inner Fold Belt

Inner Fold Belt inhabits the central portion of the Naga Hills. Distinguishing feature is a large spread of Disang capped with isolated outliers of Barail. These Palaeogene rocks folded into a series of anticlines and synclines are restricted within the Disang Thrust on the west and ophiolite belt to the east. Kohima Synclinorium in the south and Patkai Synclinorium to the north are two major synclinoria of the Inner Fold Belt. This synclinorium is positioned SSW of the Patkai Synclinorium and is situated southwest of Kohima Town consisting of broad synclines and narrow, sharp-crested anticlines, with faults trending approximately N-S. This synclinorium is flanked on all sides by the Disang and the younger groups of rocks in this structural unit lie towards the Surma Valley. It is alligned in the northwest by the Disang Thrust and in the south it merges into the eastern Surma Valley.

Corresponding to the first, second and third phases of the Himalayan orogenies, three generations of folds are recorded in the litho-units (DGM, 1978) with each generation punctuated by an interval of comparative quiescence. Formed due to orthotectonic movements during the Upper Cretaceous-Eocene period, the first set of folds is isoclinal with low plunges on both the sides with N-S to NNE-SSW axial trends forming reversal of plunge by folding later on. In combination with the first generation folds the second set of folds has NE-SW axial trends with steeply inclined axial surfaces and low plunges and directs the topographic morphometry of Nagaland. These folds perhaps correspond to the second phase of the Alpine-Himalayan Orogeny. The third set of folds is broad and open with steeply dipping axial planes and moderate plunges and trends is E-W to ESE-WNW direction. These folds are attributed to Pleistocene movements. Two sets of characteristic faults have been accounted (DGM, 1978). The earlier set, trending NE-SW, shows a conformity with the regional trend of the early folds while the later has WNW-ESE trend. These two sets interfer each other resulting in the development of large tectonic blocks.

Patkai Synclinorium

Patkai Synclinorium forms the intermediate elevated hill range of Nagaland made up of Barails and with the Disangs exposed on either side. It is observed that strike faults have affected the rocks. The Disang Thrust separates it from the schuppen belt on its northwestern flank.

Ophiolite Complex

The litho-tectonic framework implies convergence of plates whereby the Indian Plate plunge below the Burma Plate (Shan Massif) eastward forming the Indo-Burma ranges along the Ophiolite Complex of Nagaland (DGM, 1978; Imchen et al., 2014). As a result of large scale compression and faulting is distinguished whereby the drainage too is structurally controlled (Chattopadhyay et al., 1993).

CHAPTER 3

METHODOLOGY

A number of workers have undertaken LHZ mapping keeping in mind various topography and geology. The method developed by Anbalagan (1992) for preparation of LHZ maps based on landslide hazard evaluation factor (LHEF) rating scheme is implemented for the present study. The work was carried out on a Geographic information systems (GIS) platform for creation of various thematic and LHZ maps.

Starting with, the Survey of India (SoI) topographic map No. 83 K/2 (1:50,000 scale) was scanned to construct a raster file of the study area. For slope angles and relative relief, they were directly calculated from the toposheet. Whereas for identification and mapping of lineaments, IRS-1D (PAN+LISS III merged) satellite imagery was used. About 100 distinguished ground control points (GCP) were elected both on the topographic map and corresponding imagery to execute image registration. Finally the topographic map and satellite data were georeferenced in ArcGIS 9.2.

Comprehensive fieldwork and meticulous laboratory analyses were carried out to prepare the thematic maps. Fieldwork was conducted to map the litho-units, land use and land cover and groundwater conditions in the study area. Thematic maps structured in the laboratory were verified in the field and alterations where necessary were made including the lineaments that were recognized on satellite imagery. For measuring dips and strikes of the beds and joints on the field a brunton compass was used. For field mapping and transmission of data to the computer a GPS was used.

Nakamura et al. (2001) and Chi Kwang-Hoon et al. (2002) studied landslide stability analyses and prediction modeling using digital elevation models (DEM). DEM is a tool that helps in visualizing surface features and evaluates terrain conditions in 3D perception. Contours of 20 m interval were digitized and then contours at 1 m interval were generated in ArcGIS and superimposed on the existing contours. This data helps in constructing the DEM of the area representing spatial variations in altitude on which the distribution of landslides is portrayed.

Landslide prevalence were identified and marked on the thematic maps to understand the role played by each geoenvironmental factor. Then they are finally plotted on the LHZ map for confirmation of results.

Table 3.1 Data type, important features and sources of acquisition

Sl No	Data type	Features	Source
	I Topographic data		
1	Base map	Streams and roads	SoI toposheet; satellite data
2	Contour map	Contours	SoI toposheet
	II Data derived from contour map		
1	DEM	Contours and spot height	Contour map
III	**Thematic Maps**		
1	Slope angle	Slope angle	SoI toposheet
2	Relative relief	Relief	SoI toposheet
3	Lithology	Types of litho-units	Fieldwork
4	Structure	Faults, joints, fractures and shear zones	Satellite data; fieldwork
5	Groundwater condition	Dry, damp, wet, dripping, flowing	SoI toposheet; fieldwork
6	Land use/land cover	Populated land, Dense vegetation, Moderate vegetation, Sparse vegetation, Terrace cultivation	SoI toposheet; satellite data; fieldwork
	IV Collateral Data		
1	Rainfall	Rainfall	Directorate of Soil & Water Conservation
	V Field Data		
1	Lithology	Types of litho-units	Fieldwork

2	Landslide incidences	Location and details of events	Fieldwork

3.1 DEMARCATION OF FACETS

After studying the topographic map, the area was divided into a number of facets (Fig.3.1). The facets were divided considering the different hill slopes but having more or less uniform slope angles and directions. Facet boundaries were limited by ridges, spurs, gullies, stream channels and deviations in contour spacing, depending on the topography. The area has been divided into 153 facets. Each of these facets was numbered in proper sequence, starting from Kohima and ending at Mao, covering a distance of 32 km along the highway. Each individual facet boundaries were digitised and stored as polygonal features. Every facet is symbolized by these polygons and the area of a polygon entity is automatically calculated from the geodatabase in ArcGIS. Ultimately the individual facets represent the smallest mappable unit forming the basis for mapping.

3.2 LANDSLIDE HAZARD EVALUATION FACTOR RATING SCHEME

The aspects considered for LHEF rating are slope morphometry, relative relief, lithology, relationship of structural discontinuities with slope, land use and land cover and groundwater condition. The LHEF rating scheme introduced by Anbalagan (1992) is a numerical system subjective of major contributory factors of slope instability. It is studied and evaluated mainly for landslide potential area. The choice of factors opted for the maximum LHEF rating scheme are determined on the basis of their estimated impact in inducing instability. External factors like rainfall and earthquake were not included in this rating scheme. Even if they trigger slope failure and affect large areas at places, there is no data to use in the calculations. In this study a maximum value of 10, was taken for the TEHD.

LHEF rating scheme

Contributory factors	Maximum LHEF rating
Slope angle	2.0
Relative relief	1.0
Lithology	2.5

Structure	2.0
Groundwater condition	1.0
Land use & Land cover	1.5
Total	**10.0**

3.2.1 Slope angle

Slope maps provide data for planning of developmental activities so it remains an important factor in hazard analysis. Slopes to a great extent influence the intensity and extent of runoff. A slope map was set up on the basis of rate of recurrence of particular angles of slope. Allotment of slope categories is dependent on geomorphic history of the area. Slope angles for each facet were resolute by counting the number of contours in a facet and measuring the length of the facet. This is given by the formula tan θ = BC/AB, where AB is the length of the facet and BC is the altitude difference in a facet. Slopes have been classified into five different types- very gentle, gentle, moderately steep, steep and very steep. The ratings for the classification were assigned as per the scheme mentioned below.

Ratings for slope angles

Slope angle	Category	LHEF rating
< 15°	Very gentle slope	0.5
16° - 25°	Gentle slope	0.8
26° - 35°	Moderately steep slope	1.2
36° - 45°	Steep slope	1.7
> 45°	Very steep slope	2.0

3.2.2 Relative relief

Relative relief is the ruggedness of the terrain and is represented as the maximum and minimum heights within an individual facet. The relative relief can be calculated as the product of the number of contours and contour interval per centimeter length of the facet. The low values will indicate that the area has undergone very little differential erosion on the other hand high values will indicate the probable presence of faults passing through the area. It is estimated by the number of contours in a facet divided by the length of the facet multiplied by the contour interval. Relative relief

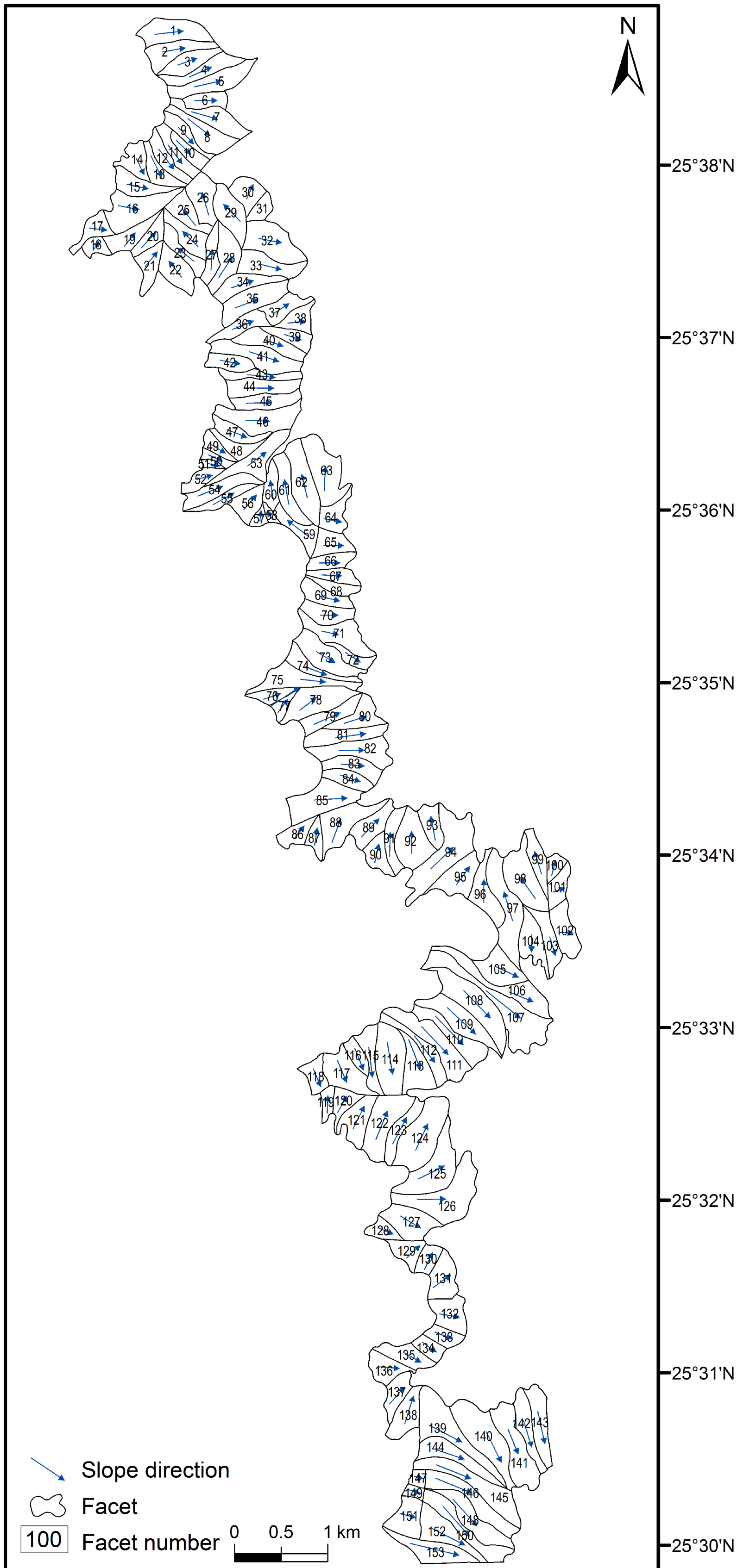


Fig. 3.1 Facet Map

maps indicate categories of relief such as low, medium, high, and very high. LHEF ratings for these factors are as follows:

Ratings for relative relief

Relative relief	Category	LHEF rating
< 100 m	Low	0.30
101 - 300 m	Moderate	0.60
> 300 m	High	1.00

3.2.3 Lithology

Different rocks are different in nature where their strengths usually depend on composition, grain size, permeability, etc. In the process the rocks are also affected by tectonism and weathering which brings about a change in their mechanical properties and composition. Weathering also greatly reduces the shearing resistance of the rocks. On the other hand soils are structure-less mass where its strength depends on grain size, permeability, compactness, etc. Hence these rocks and their weathered products were classified into several litho-units, which are given ratings as below.

Ratings for litho-units

Lithologic units	LHEF rating
Sandstone with minor shale	0.5
Shale with minor sandstone	1.5
Crumpled shale; partially weathered shale	2.0
Weathered shale; partially loose debris, loose debris	2.5

3.2.4 Structure

The stability of slopes is determined by the planes of weakness within rock masses. They may be a primary and/or secondary discontinuity which includes bedding, joints, foliation and faults. Structural discontinuities in relation to slope inclination and direction have a great control on stability of slopes. Romana (1985) defined three categories of relationships accordingly ratings were assigned:

(i) Extent of parallelism between the directions of the discontinuity or the line of intersection of two discontinuities and slope.

(ii) The steepness of the dip of discontinuity or the plunge of the line of intersection of the two discontinuities.

(iii) The difference in the dip of the discontinuity or the plunge of the line of intersection of the two discontinuities to the inclination of the slope.

These relationships were used in this study. The inferred depth of soil cover was implemented for representing ratings in soil covered areas.

Ratings for structural disposition of rocks

Relationship of discontinuity with slope		LHEF rating
I Relation of parallelism between slope and discontinuity		
1	> 30°	0.2
2	21°- 30°	0.25
3	11°- 20°	0.3
4	6°- 10°	0.4
5	< 5°	0.5
II Relationship of dip of discontinuity and angle of slope		
1	> 10°	0.3
2	0°- 10°	0.5
3	0°	0.7
4	0°- (-10°)	0.8
5	< (-10°)	1.0
III Dip of discontinuity		
1	< 15°	0.2
2	16° - 25°	0.25
3	26° - 35°	0.3
4	36° - 45°	0.4
5	> 45°	0.5
IV Thickness of soil cover		
1	< 5 m	0.65
2	6 - 10 m	0.85
3	11 - 15 m	1.3
4	> 16 m	2.0

3.2.5 Groundwater condition

In hilly terrain groundwater generally does not have a uniform flow pattern, but branches out along structural discontinuities in rocks. Majority of the area is made up of Barail sandstones with intercalations of thin papery and splintery shales, which are highly jointed and much of which are fractured and crushed. As monsoon sets in, water seepage in the subsurface rise high to seep at various places along the hill slopes. Hence it is a setback to evaluate the behaviour of groundwater in hilly regions over large areas. In order, to make work easier assessment on the nature of surface indications of the actions of groundwater will provide important information on the stability of hill slopes, for hazard mapping purposes (Anbalagan, 1992). Surface indications were categorised and ratings awarded as below.

Ratings for groundwater conditions

Category	Rating
Dry	0.0
Damp	0.2
Wet	0.5
Dripping	0.8
Flowing	1.0

3.2.6 Land use and land cover

Land use subjects to the use of land for human exploits while land cover subjects to the natural land cover in an area. This category includes all the settlements, agricultural land, open forests, etc. The consistency of slopes depends to a great extent on how land is used for different practices and what type of land covers the area. The land use and land cover map of the study area includes five categories, as shown below with the rating scheme. These have been mapped from satellite imagery (LISS III + PAN merged) by deducing their tonal and textural features, and verifying them in the course of fieldwork.

Ratings for land use land cover

Category	Rating
Populated land	0.65

Dense vegetation	0.80
Moderate vegetation	1.00
Sparse vegetation	1.20
Terrace cultivation	1.50

3.3 TOTAL ESTIMATED HAZARD

LHEF ratings for every individual causative factor including categories were calculated facet-wise. The ratings for each individual factors were added up to acquire the TEHD. Thus, TEHD = ratings of slope morphometry + relative relief + lithology + structure + groundwater condition + land use / land cover. Total of every individual facet signifies the net wise possibility of instability. A rating of 10 indicates the maximum value of TEHD.

3.4 LANDSLIDE HAZARD ZONATION

LHZ relates to the separation of an area into diverse categories whereby the area is graded according to the degree of definite or potential hazard from landslides on slopes. LHZ maps help in recognizing and delineating landslide probable areas, which thereby help in averting prone sites, leading to minimizing of risk and loss. Therefore a LHZ map of the study area is generated on the basis of the distribution of the TEHD values following Anbalagan (1992). The different categories of hazard for designated TEHD values are as follows:

TEHD Values	Description of zones
< 3.15	Very low hazard
3.15 - 4.50	Low hazard
4.60 - 5.40	Moderate hazard
5.50 - 6.75	High hazard
> 6.75	Very high hazard

3.5 ROCK AND SLOPE MASS RATING

Bieniawski (1979) put forward a rock mass classification called the rock mass rating (RMR), which directed to the development of the slope mass rating (SMR) by Romana (1985), on which the present study is based. The RMR is calculated by evaluating values for five parameters such as strength of intact rock, rock quality designation, spacing and condition of discontinuities, and water inflow through discontinuities (Table 3.2). Rock mass classes determined from total ratings are given in (Table 3.3).

To have a better and clearer understanding of stability conditions in this area, studies of fresh-cut slopes along and around this highway was done. Two major slides in the area were studied in detail. Then remedial measures for these areas are provided in addition to general mitigation measures. About forty rock samples were collected from each location and analyzed using a point load index tester (PLIT). Averages of these samples were taken to determine their strengths.

Table 3.2 Classification parameters and ratings (after Bienawski, 1979)

Parameters		Ranges of values				
1. Strength of intact rock material (MN/m^{-2})	Point load strength index	>10	4-10	2-4	1-2	
	Uniaxial compressive strength	>200	100-200	50-100	25-50 10-25 3-10 1-3	
Rating		15	12	7	4 2 1 0	
2. Drill core quality RQD (%)		90-100	75-90	50-75	25-50	<25
Rating		20	17	13	8	3
3. Spacing of joints		>3 mm	1-3 mm	0.3-1 mm	50-300 mm	<50 mm
Rating		30	25	20	10	5
4. Condition of joints		Very rough surface; not continuous; no separation	Slightly rough surface; separation <1mm; hard joint wall rock	Slightly rough surface; separation <1mm; soft joint wall rock	Slickenside surface; gouge <5mm; thick; joints open; 1.5mm; continuous	Soft gouge <5m; joints open; 1.5m; continuous
Rating		25	20	12	6	0
5. Groundwater	Inflow per 10 m tunnel length (1min^{-1})	None	<25	25-125	>125	
	Ratio of joint water pressure/major principal stress	0	0.0-0.2	0.2-0.5	0.5	
	General conditions	Completely dry	Moist (interstitial water)	Water under moderate pressure	Severe water problem	
Rating		10	7	4	0	

Table 3.3 Rock mass classes

Rating	100-81	80-61	60-41	40-21	<20
Class No	I	II	III	IV	V
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock

The strengths of rocks were measured using a point load testing machine. The point load strength index (I_s) was calculated from the values obtained in the PLIT using the relation $I_s= P/D^2$

where P - pressure obtained at failure

D - diameter of sample

Deere et al. (1967) estimated rock quality designation index (RQD) that provides a quantitative estimate of rock mass quality from drill core logs. Palmström (1982) projected RQD from the number of joints per unit volume, given by the equation:

$$RQD= 115 - 3.3J_v$$

whereJ_v, designates volumetric joint count where it represents the sum of the number of joints per unit length for all joint sets.

The joint condition is measured from the inbuilt surface smoothness, unevenness or waviness with subject to the plane of the joint. These conditions can be done directly from the field by touch as very rough, rough, slightly rough, smooth and polished. Joint roughness is designed numerically from the joint roughness coefficient (JRC), which is matched to the appearance of a discontinuity surface with the profile of Barton and Choubey (1977). Groundwater condition is an additional important parameter in considering slope stability conditions. Visual observations and studies for groundwater conditions were done for this area then estimating and assigning ratings were done accordingly. To determine the mode of failure and to adjust ratings for slope stability the sum of all the five parameters were taken giving the RMR value for any particular slope facet. Stereographic analyses of discontinuities were also assessed. The adjustment ratings F_1, F_2 and F_3 for joints were focused on joint trend (α_j), slope face trend (α_s), joint dip angle (β_j) and slope angle (β_s) of Romana (1985). The value of F_4 was calculated relating to natural slopes.

Thus SMR was attained from the RMR by adding a factorial adjustment factor depending on the joint-slope relationship and adding a factor for the natural slope. Here,

$$SMR = RMR + (F_1 x F_2 x F_3) + F_4$$

1) F_1 depends on parallelism between strikes of joints and slope faces. Values range from 1.00 to 0.15. These values match the relationship $F_1 = (1\text{-SinA})^2$, where A denotes the angle between the strikes of slope faces and joints.
2) F_2 refers to joint dip angle in the planar mode of failure. Its value ranges from 1.00 to 0.15 and matches the relationship $F_2 = \tan^2 \beta j$, where βj denotes the joint dip angle.
3) F_3 reflects the relationship between slope face and joint dips.
4) F_4 denotes the adjustment factor for the method of excavation that has been fixed empirically.

The adjustment rating and stability classes are represented in Tables 3.4 and 3.5.

Table 3.4 SMR rating system (Romana, 1985)

Case	Very favorable	Favorable	Fair	Unfavorable	Very unfavorable
P I αi-αs I T I αi-αs-180 I P/T F_1	>30° 0.15	30°-20° 0.40	20°-10° 0.70	10°-5° 0.85	<5° 1.00
P I βi I P F_2 T F_2	<20° 0.15 1	20°-30° 0.40 1	30°-35° 0.70 1	35°-45° 0.85 1	45° 1.00 1
P βi-βs P βi+βs T F_3	>10° >110° 0	10°-0° >110°-120° -6	0° >120° -25	0°-(-10°) -50	<-10° -60
Method	Natural slope	Pre-splitting	Smooth blasting	Regular blasting	Deficient Blasting
F4	+15	+10	+8	0	-8

P = plane failure αs = slope dip direction αi = joint dip direction

T = toppling failure βs = slope dip βi = joint dip

$SMR = RMR + (F_1 x F_2 x F_3) + F_4$

Table 3.5 SMR classes (after Romana, 1985)

Class No	**V**	**IV**	**III**	**II**	**I**
SMR	0-20	21-40	41-60	61-80	81-100
Description	Very poor	Poor	Fair	Good	Very good
Stability	Very unstable	Unstable	Partially stable	Stable	Fully stable
Failures	Large planar or soil-like	Planar or large wedge	Some joints or many wedge	Some blocks	None
Support	Re-excavation	Extensive corrective	Systematic	Occasional	None

3.6 KINEMATIC ANALYSES

Kinematic analyses facilitates in proving the possible modes of slope failure in a jointed rock mass. To verify the joints sets that control failure mode, about 200 joint trends were taken from the perimeter of the two slide zones and plotted in GEOrient software (R.J. Holcombe, University of Queensland, Australia) to generate polar density and contour diagrams. From this data, stereographic projections for the joints were created. Kinematic analyses were executed from the data generated from joint projections using the Markland's test (Markland, 1972). This test was initially modified by Hocking (1976) and later by Cruden (1978) and Hoek and Bray (1981). The overall study proposes to determine the probable mode of failure in the slide zones.

3.7 GEOTECHNICAL ANALYSES

Geotechnical analyses were conducted to evaluate the geotechnical parameters of soils in the unstable areas. Soil samples were collected from various sites and depths, and moisture contents determined by the speedy moisture tester.

3.7.1 Laboratory investigations

Moisture content test

The soil sample is heated for 24 hours at 105 °C. The moisture content is calculated using the following expression:

$$W = \frac{W_2 - W_3}{W_3 - W_1} X100$$

Where,

W_1 = Weight of the container

W_2 = Weight of container and wet soil

W_3 = Weight of container and dry soil

Liquid limit test

The liquid limit is determined using a Casagrande liquid limit apparatus.120 g of thoroughly mixed, air dried soil (425 micron) was thoroughly mixed with distilled water and kept overnight. A portion of the soil mixture was remixed to form a smooth paste for experimentation. A groove was made in the soil paste with a grooving tool (IS: Type A) firmly through the centre of a cup to obtain a groove of proper dimensions. By uniformly rotating the handle at two revolutions per second, the cup was raised and dropped repeatedly till the two portions of the soil separated by the groove flowed together to close the groove for a length of 12 mm. The numbers of blows from the revolution counter were then noted and moisture content determined. The procedure was repeated four more times with higher water contents. The number of blows required to close the groove was 25±10.

Plastic limit test

It refers to the minimum water content at which a soil will just begin to crumble when rolled into a thread approximately 3 mm in diameter. About 20 g of air dried soil (passing through 425 micron sieve) was thoroughly mixed with distilled water to make it plastic enough to be shaped into a ball. This was left for some time to mature. About 8 g of the plastic soil was rolled on a glass slab into a thread of uniform diameter. When the diameter of the thread decreased to 3 mm, the specimen was kneaded and rolled out again. The process was repeated till the thread crumbled at 3 mm diameter.

Determination of index properties

Plasticity Index (I_P)

The range of consistency within which a soil exhibits plastic properties is called the plastic range, which is indicated by the plasticity index. The plasticity index is defined as the numerical difference between the liquid limit (W_L) and the plastic limit (W_P) of a soil:

$$I_P = W_L - W_P$$

In the case of sandy soils, the plastic limit should be first determined. When the plastic limit cannot be determined, the plasticity index is reported as *NP* (non-plastic). When the plastic limit is equal to or greater than the liquid limit, the plasticity index is zero.

Liquidity Index (I_L)

The liquidity index or water-plasticity ratio is the ratio, expressed as a percentage, of the natural water content (W) of a soil minus its plastic limit (W_P), to its plasticity index (I_P):

$$I_L = \frac{W - W_P}{I_P}$$

Consistency Index (I_C)

The consistency index or the relative consistency is defined as the ratio of the liquid limit (W_L) minus the natural water content (W) to the plasticity index (I_P) of a soil:

$$I_C = \frac{W_L - W}{I_P}$$

Consistency index is useful in the study of the field behavior of saturated fine grained soils. Thus, if the consistency index of a soil is equal to unity, it is at the plastic limit. Similarly, a soil with I_C= zero is at its liquid limit. If I_C exceeds unity, the soil is in a semisolid state and will be stiff. A negative consistency index indicates that the soil has natural water content greater than the liquid limit and hence behaves just like liquid.

Flow Index (I_f)

The flow index or the slope of the curve can be determined from the relation:

$$I_f = \frac{w_1 - w_2}{\log_{10}\frac{n_2}{n_1}}$$

w_1 - water content corresponding to blows n_1

w_2 - water content corresponding to blows n_2

Selecting the values of n_2 and n_1 corresponding to the number of blows over one log-cycle difference, $\log_{10}\frac{n_2}{n_1}$ becomes equal to unity, and hence I_f becomes equal to the difference between the corresponding water contents. Thus, if the flow curve is extended at either end so as to intersect the ordinate corresponding to 10 and 100 blows the numerical difference in water content at 10 and 100 blows directly gives the flow index.

Toughness Index (I_T)

The toughness index is defined as the ratio of the plasticity index to the flow index:

$$I_T = \frac{I_P}{I_f}$$

Shrinkage limit

It is the lowest water content at which a soil can still be completely saturated.

Determination of shrinkage factors of soil

Shrinkage test was carried out to determine moisture content, shrinkage limit, shrinkage ratio and volumetric shrinkage. About 100g of soil passing through a 425 micron sieve was mixed thoroughly with distilled water to prepare a paste. The volume of a clean shrinkage dish was determined by placing it in the evaporating dish, which was completely filled with mercury. Excess mercury was removed by pressing the plain glass plate firmly on its top, taking care that no air was entrapped. By carefully transferring the mercury of the shrinkage dish to the evaporating dish, the mass of mercury was determined by dividing this weight by the unit weight of mercury. The volume was obtained using a measuring cylinder. The inside of the shrinkage dish was coated with a thin layer of Vaseline. The soil paste (about one-third of the volume of the dish) was placed in the centre of dish. The dish was tapped gently on a firm cushioned surface to allow the paste to flow towards the edges. Another equal installment of the paste was placed in the dish and the above procedure repeated. The process was continued till the paste was compacted and all the entrapped air was brought to the surface such that the dish was completely filled. The weight of the shrinkage dish and wet soil pat was immediately taken and then dried at 105°C. The dish was then cooled and the weight of the dry soil pat taken.

The glass cup was put in the evaporating dish and filled with mercury. The oven-dried soil pat was then placed into the mercury. The displaced mercury was carefully collected and mass determined to an accuracy of 0.01g. The volume of the dry soil pat was then determined by dividing this mass by the density of mercury.

3.7.2 Calculations

Moisture Content

Calculate the moisture content of the soil at the time it was placed in the dish expressed as a percentage of the dry weight of the soil as follows:

$$M = \frac{W - W_0}{W_0} X100$$

Where M = Moisture content of soil when placed in the dish

W = Weight of wet soil pat obtained by subtracting the weight of the shrinkage dish from the weight of wet pat and dish

W_0 = Weight of the dry soil pat obtained by subtracting the weight of the shrinkage dish from the weight of the dry pat and dish

Shrinkage Limit

Calculate the shrinkage limit 'S_L' from the data obtained in the volumetric shrinkage determination, as follows:

$$S_L = M - \frac{V - V_0}{W_0} X100$$

Where S_L = Shrinkage Limit in %

M = Moisture content of wet soil, in percentage of the mass of oven dried soil

V = Volume of wet soil pat in ml

V_0 = Volume of dry soil pat in ml

W_0 = weight of oven dried soil pat in g

As an alternative method the shrinkage limit can be calculated as follows, when the specific gravity 'G_0'of the soil is known and shrinkage ratio 'SR' are known:

$$S_L = \left[\frac{1}{SR} - \frac{1}{G_0}\right] X100$$

Where SR = Shrinkage ratio

G_0 = Specific gravity for the fraction used in the test

Shrinkage Ratio

Shrinkage ratio is defined as the ratio of a given volume change expressed as a percentage of dry volume, to the corresponding change in water content above the shrinkage limit expressed as a percentage of the weight of the oven dried soil:

$$SR = \frac{W_0}{V_0}$$

Volumetric Shrinkage

It is defined as the decrease in one dimension of a soil mass expressed as a percentage of the original dimension, when the water content is reduced from a given value o the shrinkage limit.

$$V_S = (W_1 - S_L)SR$$

WhereW_1 = given percentage of water content

3.8 DIRECT SHEAR TEST

This is a simple and commonly used test and is performed in a shear box apparatus. The apparatus consists of two pieces of shear box of square cross section namely: the lower-half and the upper-half. The lower-half is rigidly held in position in a container which rests over by a geared jack, driven either by electric motor or by hand, and the upper-half of the box butts against a proving ring. The soil sample is compacted in the shear box, and is held between metal grids and porous stones (or plates). The upper-half of the specimen is held in the upper box and the lower-half in the lower box, and the joint between the two parts of the box is at the level of the centre of the specimen. Normal load is applied on the specimen from a loading yoke bearing upon steel ball of pressure pad. When a shearing force is applied to the lower box through the geared jack, the movement of the lower part of the box is transmitted through the specimen to the upper part of the box and hence on the proving ring, and its deformation indicates the shear force.

The soil sample can be compacted in the shear box by clamping both the parts together with the help of screws. These screws are, however, removed before the shearing force is applied. Metal grids, placed above the top and below the bottom of the specimen have linear slots or serration to have proper grip with the soil specimen, and are so oriented that the serration are perpendicular to the direction of the shearing force.

Apparatus:

1. Shear box equipment consisting of
    - a) Shear box; divided into two parts horizontally, with suitable spacing screws,
    - b) Container for shear box
    - c) Grid plates (two pair one plain and the other perforated)
    - d) Porous stones, one pair
    - e) Base plate
2. Loading frame, to distribute the load from the yoke over the specimen, normal to the shear plane.
3. Set of weights for normal load.
4. Proving ring with dial gauge to measure the shear force.
5. Micrometer dial gauge, to measure horizontal and vertical displacements during shear.
6. Spatula, straight edge, sample trimmer etc.
7. Stop watch.

Procedure:

1. The undisturbed specimen is prepared by pushing a cutting ring in the undisturbed soil specimen obtained from the field. The square specimen is then cut from the specimen so obtained.
2. In order to obtain remolded specimen of cohesive soil, the soil may be compacted to the required density and water content, in a separate bigger mould. The sample then extracted and trimmed to the required size. Alternatively, the soil may be compacted to the required density and water content directly into the shear box after fixing the two halves of the shear box together by means of the fixing screws.
3. Non- cohesive soil may be tamped in shear box itself with the base plate and grid plate or porous as required in place at the bottom of the box.

In all the three cases mentioned above, water content and dry density of the soil compacted in the shear box should be determined.

Undrained test:

1. The shear box with the specimen, plain grid plate over the base plate at the bottom of the specimen, and plain grid plate over the top of the specimen should be fitted into position. The serrations of the grid plates should be placed at right angle to the direction of shear. As the porous stones are not used in the undrained test, plain plates of equal thickness should be placed, one at the bottom and the other at the top of the two grids, so as to maintain the shear plain in the sample in the middle of its thickness. Place the loading pad on the top of the plain plate. Both the parts of the box should be tightened together by the fixing screws.
2. Put water inside the water jacket so that the sample does not get dried during the test.
3. Mount the shear box assembly on the load frame (or shearing machine). Set the lower part of the shear box to bear against the load jack and the upper part of the box to bear against the proving ring. Set the dial of the proving ring to zero.
4. Put the loading yoke on the top of the loading pad, and adjust the dial gauge to zero to measure the vertical displacement in the soil sample. Put proper normal weight on the hanger of the loading yoke, so that this weight plus the weight of the hanger equals the required normal load. Note the reading of the vertical displacement dial gauge.
5. Remove the locking screws so that both the parts are freed to move against each other. By turning the spacing screws, raise the upper part slightly above the lower part by about 1 mm.
6. Conduct the test by applying horizontal shear load to failure or to 20% longitudinal displacement, whichever occurs first. The rate of strength may vary. Start the stopwatch at the start of the application of the shear load. Take the reading of proving ring dial gauge, longitudinal displacement and vertical displacement gauge at regular time intervals.
7. At the end of the test, remove specimen from the box and determine its final water content. The above steps are repeated on three or four identical specimen, under varying normal loads.

Consolidated Undrained test

In this test instead of plain grid plates, perforated grid plates are used. And the shear test should be conducted only after complete consolidation has been occurred under a particular normal stress. And procedure of undrained test is performed.

Consolidated Drained test

The shear box is assembled with sample, perforated grid plates and porous stones, as in consolidated undrained test. The sample is allowed to consolidate under the normal load. After the application of the normal load, vertical compression of the soil with time should be recorded, as is done in the consolidation test.

This test was performed in a shear box apparatus, which consists of two pieces of shear boxes of square cross section. The lower half is rigidly held in position in a container which rests over a geared jack, driven by an electric motor. The upper half of the box butts against a proving ring. The soil sample was compacted in the shear box and held between metal grids and porous plates. The upper half of the specimen was held in the upper box and the lower half in the lower box. The joint between the two parts of the box was at the level of the centre of the specimen. Normal load was applied on the specimen from a loading yoke bearing upon a steel ball pressure pad. When a shearing force was applied on the lower box through the geared jack, the movement of the lower part of the box was transmitted through the specimen to the upper part of the box, and hence on the proving ring. The deformation indicates the shear force.

CHAPTER 4

LITERATURE REVIEW

INTRODUCTION

An integrated anthology of updated literature in interpretation and justification of the geological pattern of Nagaland has been meager owing to its remoteness and inaccessibility, and several other issues. The most primal literature recognized was by Oldham (1883), who submitted a study on the geology of Kohima and parts of northern Manipur. After about three decades later, Pascoe (1912) shared his discourse on geological remarks between Dimapur and Saramati. Evans (1932) gave information's on the Tertiary succession of Assam also on the tectonics of Nagaland. Investigations and findings on the stratigraphy, structure, and conditions of deposition of the Tertiaries of Upper Assam and Nagaland was convoluted by Mathur and Evans (1964). Sarmah (1989) detailed its focus on Disang and Barail sediments of Kohima. Agarwal and Shukla (1996) shared their overview and explained that the drainage in this region is structurally controlled as most of the rivers flows along the lineaments trending NE-SW and NW-SE. Pillai et al. (2008) have indicated about the identification, distribution and significance of clay minerals in the Disang shale of Kohima and further discussed in his conclusion that the Disang silica clastics were derived from complex sources. Also adding that the sediments were possibly as a result of severe weathering and rapid erosion from orogenic sources where climatic conditions are humid (Imchen et al., 2014). Aier et al. (2011a) is of the opinion that the region is assigned to ongoing tectonism.

Sondhi (1941) made a first attempt to comprehensively study landslides along the Dimapur-Manipur. Sharda and Bhambay (1980) performed environmental and geo-scientific studies to present geo-technical and slope classification maps of Kohima town. Initial landslide studies were performed along the Dimapur-Mao section by Anand (1988). In 1990, the Directorate of Geology and Mining (DGM) worked on an investigative study on the major landslides in the Alempang ward of Mokokchung town. Lotha (1994) and Walling et al. (2005) deliberated the Chiepfütsiepfe slide of Kohima with their purpose of providing improvement measures. Bhattacharjee et al.

(1998) also added an understanding on landslides through the observation and findings on land instability along portions of NH 39. The Central Road Research Institute (2000a) revealed the weak zones between Chumukedima and Maram. DGM (2001) identified instability in parts of Mokokchung town during their geo-hydrological, geo-technical and geo-environmental studies in that of the region. Mitigation measures for the Chokidzü debris slide, located on the South of Kohima town was submitted by Kemas et al. (2004). A groundwork geological report of the Mao area slide with improvement procedures was appropriately recommended to the Border Roads Organization by Thong et al. (2004). A LHZ map for the NH 39 to Manipur was prepared by Aier (2005) who also gave all-inclusive information on the Lalmati (enroute Dimpaur-Kohima) slide to identify its causes. DGM (2005) inspected the slides that occurred on 25th June 2005 at Mokokchung town. Walling (2005) arranged a LHZ map of Kohima town by means of RS and GIS, and submitted mitigation measures in those areas found to be weak zones. Hiese (2005) painstakingly deliberated Kohima town and its conditions to build a landslide risk map. Aier and Thong (2006) assembled information on major subsidence at the Lumami Headquarters of the Nagaland University. Thong et al (2006a) and Thong et al. (2006b) worked on a detailed project reports on land instability along part of the NH 39 and Kohima town. Thong et al. (2007) gave a detailed description on the 179 km slide along the NH 39. Sothu (2008) deliberated instability along the NH 150 between Kohima and Chakhabama providing stability solutions for some portions of the highway affected by shear zones. Aier et al. (2009a & 2009b) also gave a detailed version on SMR and kinematic analyses along some section of NH 61 and also did a further exploration in 2012 on land instability at Merhülietsa colony of Kohima town. Nokmatongba et al. (2011) did an assessment on debris slide in the Artang Ward of Mokokchung town. Supongtemjen et al. (2012) examined surface instability between Kohima and Zhadima to conclude on a detailed mitigation measures.

Landslides is caused as a result of a series of occurrences that generate a downward and outward movement of slope-forming material made up of rocks, soils or a mixture of these rudiments. The materials may shift by falling, sliding, spreading, collapsing or flowing (USGS, 1981). Mass movements consist of different kinds with their own discrete type and characteristics. It can be concluded that while some movements are rapid others remain significantly unnoticeable and slow, and can only be recognized in the alteration of surface expressions.

One typical character, ‘Creep’ is a slope movement involving viscous soil and rock materials, which moves downward very slowly and its movement is imperceptible. On the other hand a ‘landslide’, refers to a failed mass moving along a planar or a curved surface at a considerable rate. While ‘Falls’ refers to an abrupt downward movement of loosened material or solid rock from cliffs. Movements of unconsolidated material in the plastic or fluid state are ‘Flows’. ‘Subsidence’ refers to the vertical downward movement of unconsolidated material with no horizontal flow. Current landslide arrangement have accepted the categorization of Varnes (1978), which was customized by Cruden and Varnes, (1996). The types of material involved in an individual slide or flow commonly corresponds to well-defined topographic settings. Earth slides and flows are common on more gentle slopes with less vegetation, on the foothills and river courses. In the steeper, mountainous areas debris slides and flows is observed it also occur in areas covered by vegetation. Rock slides and flows transpires in previously steep glaciated high valleys that generally lack vegetative cover, and along other very steep slopes that are commonly greater than 50 degrees.

Landslides are of two basic types: First, includes those slides due to mechanical grounds related to increase in hydrostatic pressure and erosion. Terzaghi (1950) suggest that where silt is interbedded with sand, or clay with silt, water percolates through the coarser porous units and gets trapped above the fine grained units. The significant enhancement in pore pressure between the sand and silt grains forces the particles apart, reducing inter-grain friction. As gravitational forces acting on the grains are opposed by inflated buoyancy, the particles on steep slopes loosen up and become unstable and ultimately slopes fail. Schmidt and Beyer (2001) harangued that internal controlling factors are consistent primarily to lithological, structural and morphometric quality of the slope system.

Second category takes into account those slides by physical and/or chemical changes in the soil. Under this landslides are categorised as those incidences due to natural causes and those related to anthropogenic activity. In most cases, a single factor cannot be accredited to the cause of a landslide. Caine and Mool(1982) are of the view that basically landslides are complex hybrids between several classes. Landslides caused by neotectonic activities like earthquakes and reactivation of faults and thrusts, water action and denudational processes acting on the surface of the earth are classified as natural landslides. Brabb et al. (1972) and Nilsen and Brabb (1972) opined that any conclusion of a region should consist of an analysis of slope stability, integrating factors such as degree of slope, bedrock, soil characteristics, seismic triggering of landslides and other factors. According to Nilsen et al. (1976) a mixture of various factors induces landslides, which may occur due to gradual or sudden changes on a slope. Sahai (1993) is of the view that weak lithology, steep slopes, poor vegetative cover and abnormal rainfall are the causes of slope instability. Corominas and Moya (2003), Flageollet et al. (1999) and Hardenbicker (2001) concluded that abundant moisture in slope systems is the main external agent triggering high-magnitude slope failure. Brunsden (1993) deliberated that landslides are triggered mainly by seismic activity, ground subsidence and erosion at the base of the slope or change in water regime. Some external factors that can lead to landslides may also be due to intense rainfall, ground vibrations due to earthquakes, subsurface water level changes, storm waves and rapid stream erosion (Dai et al., 2002). Towhata (2007) too says that increases in moisture content can trigger slope failure. Dortch et al. (2008) follows that monsoon precipitation is the main agent for enhancing large landslides in the Himalayan region. Sharma et al. (1996) suggested that landslides are the fastest of all mass movements and create great vulnerability in mountainous terrain. It has been acknowledged that landslides are common in young and active mountain belts. Petley and Reid (1999) also points out that when mountain chains are uplifted landslides are prone.

Human-induced landslides are called ‘anthropogenic’ or ‘technogenic’. Anthropogenic landslides are connected with urbanisation and deforestation while technogenic landslides to mining, public utility activities and construction of roads, dams, bridges, etc. (Gray, 1973; Swanson and Dyrness, 1975; Swanston and Swanson, 1977) suggested that forest destruction/deforestation and road construction trigger major landslides. Also poor road construction accompanies weakening of hillsides and accumulation of large amounts of debris as most road construction in the Himalayas is substandard, which has led to increased landslide incidences (Bhandari, 1987; Ives, 1987; Valdiya, 1987). Kumar et al. (1995) blamed mass wasting to the existence of huge deposits of unconsolidated material on steep hill slopes. Moghaddas and Ghafoori (2007) condemn road construction for triggering landslides, in addition to factors such as earthquakes, intense rainfall, etc. Akgun et al. (2008) point to amplified cultivation for surface instability. Aier et al. (2009) attribute that the load and vibrations due to heavy vehicles on the road along the weak slopes also contributes to slope failure.

Landslides are accompanied by rapidity, severity and shortness of duration that may involve death, damage to life and property, disruption of communication technology, sanitation and transportation systems, etc. Hence, a better understanding of its disposition and causes is of the essence for suggesting mitigation and remedial measures. With progression and increase in technological research and studies, information on landslides also has become more reachable and widespread. Most studies highlight methodologies involving advanced hypothesis and concepts. In recent years GIS, with its astounding information arrangement and spatial data processing ability, gained much confidence in this area. GIS is a method using computer-assisted system for the attainment, storage, analysis and display of geographical data. It supplies strong functions in spatially disseminated data processing and analysis. Gupta and Joshi (1990) and Saha et al. (2002) worked on GIS based LHZ mapping in the Himalayas. After meticulous studies on earlier works, Ramasamy and Muthukumar (2008) arrived with a methodology related to advanced concepts available in GIS. Here GIS layers were created for contributing geosystems like lineament density, geomorphology, drainage density, slope, regolith, land use / land cover, etc. Landslide datas were integrated with a variety of datasets, and based on frequency of landslide events threshold principles for each geosystem were acknowledged resulting to increased support of landslide investigations from Governmental and other organizations and agencies. Hence, mapping of landslides and landslide-prone topography on both regional and local scales has achieved continuing status.

4.1 Slope and relative relief

Slopes plunge due to a variety of reasons including slope angle, water content, type of earth material involved and local environmental factors such as climate. Slope is a significant consideration that plays a necessary role in landslide analysis; hence slope maps provide beneficial data for planning and developmental activities. The amount and degree of runoff are subjective of slope.The relative relief is to estimate the ruggedness of the terrain. 81% of landslides activities have occurred on slopes that are greater than 30°. Debris flows take place on slopes with angles greater than 30° (Terzaghi, 1950). Lithology and structure plays important role in the development and disposition of slopes (Emelyanova, 1977). Combinations of these factors furnish a variety of slopes evident by favourable and unfavourable terrain setting (Shah and Jadhav, 1987). Slope instability evaluation should also be related to examination of terrain conditions at paleoslide sites (Westen, 1993). Anthropogenic activities disturb the natural symmetry of the environment; leading to destabilisation of slopes opines Mehrotra et al. (1993). Soeters and Westen (1996) insists that slope instability is the product and results of geodynamic processes, vegetation and human activity. According to CRRI (2000b) instability of slopes complies due to composite relations of factors such as geotechnical, geological, hydrological, climatic and human activities. Aier (2005) figures out that the prime factors controlling slope stability are lithology, structure and drainage. The impact of slope instability on landscape development is hindered by heterogeneity in lithology, climate and tectonic forces common to many active tectonic regions (Roering et al., 2004).

Slope instability is characterised by downward and outward movements of materials. With increase in the inclination and height of sloping surfaces, shearing stresses rise up to bring failure. Few essential principles in determining slope stability are the degree of fracturing and shearing, and attitude of beds or joints in relative to slope geometry. (CRRI, 2000a) indicates that this is generally due to high pore-water pressure and large slope deformations. Choubey and Lallenmawia (1987) states that failure of natural slopes exposes surface vegetation and other soil cover revealing the slope to further erosion by surface and subsurface waters. The diverse nature of slope is complex, and tolerating their behaviour is difficult. Slopes are a combination of vastly irregular surfaces that cannot be illustrated by a simple mathematical equation (Sharma et al., 1996). In addition, Fujita et al. (1976) and Fujita (1980) simplifies that landslide incidences are sternly coupled with the inclination of slope. Slopes are normally gentle to moderate, becoming steeper near valleys. A landslide increases at the toe of a slope as the driving forces exceed the resisting forces with normal shear strength (Veder and Hilbert, 1980). Piteau and Peckover (1989) adds that concave slopes are more stable than those that are convex and hence, slopes cut in mountainous terrain for highways are frequently convex and therefore more unstable. The safety factor for a slope is the portion of the sum of resisting forces that proceed to prevent failure, to the sum of the driving forces that tend to cause failure. Hence, slope stability relies on the forces that tend to oppose failure compared with those that tend to cause failure. Kumar et al. (1995) highlighted new viewpoint that major slides occur in the middle slopes. Slope transformation due to anthropogenic activity is a vital reason in slope instability (Thigale et al., 1998). Tiziano (2003) contributed to monitoring and arrangement for slope stabilization. Varied combinations of these feature brings about a collection of slopes marked by constructive and adverse terrain conditions (Shah and Jadhav, 1987). The fundamental setting for slide initiation are confirmed by a multi faceted contact of environmental features like geological, geomorphologic, hydro meteorological, and hydrogeological. Most important factor is the geomorphologic condition, that is, the degree of relief (Matula, 1969). Low values of relief consigns that the area has undergone very little differential erosion whereas high values indicates the presence of longitudinal or transverse faults running through the area.

Water from precipitation penetrates through the cracks causing swelling of the adjoining soils which leads to decrease in shear strength and cracks develop (Nishida et al, 1979; Crozier, 1989). Slopes can stay stable for a long period of time and then suddenly lose their stability due to loss of shearing strength.

On normal circumstances, hill-slope systems adjust to fluctuations in relieving energy by soil creep, possibly due to recurring undercutting caused by streams and surfacial erosion, often supported by biogenic procedure. Due to rate of change, the hill-slope system is forced to store excess relief energy and becomes over-steepened. An over-steepened slope at times become susceptible to instabilities such as heavy rainfall, vibration, and biogenic impact like forest fire or human construction and settlement in its environment. Such disturbances can push the hill-slope system ahead of its intrinsic threshold of stability. Thus slope fails, working rapidly to a new morphological state, often of greater stability (Haigh, 1988).

Slopes often depend on climatic conditions and landslides a common feature in areas of intense tectonic activity with unfavourable climatological and geological conditions. An important part controlling slope failure is incessant rainfall, but its action is different on natural slopes and disturbed slopes. Shear strengths of slope materials dwindles when water enters cracks, causing swelling of the adjacent soils and leading to cracks (Nishida et al, 1979; Crozier, 1989). Even though slopes remain stable over long periods, they may suddenly lose their stability once shearing strength of the slope is condensed. It is now well predictable that rainfall commonly triggers landslides. Towhata (2007) is of the view that increased moisture content leads to slope failure, though moisture content need not be an objective for monitoring.

4.2 Lithology

Slopes are usually made up of intricate rocks of varied geologic character. The strength of the constituent minerals and the temperament of the mineral assemblage are vital properties. Necessarily rocks are weak corresponding to the bonding strength and relation between the mineral assemblages of the mineral is weak. (Piteau and Peckover, 1989) insists that shearing resistance and other strength properties are poorly affected by weathering. Planes of weakness on rock masses depressingly affect rock slopes to a great extent and important behavioural differences exist between rocks and soils. A rock mass is an assorted and irregular medium composed essentially of different solid blocks that are removed by discontinuities. Hence rock masses fall short along surfaces of pre-existing discontinuities but do not take place in intact rock unless the rock is feeble or ineffectual.

Soil is a homogenous and constant medium of loose particles where failure takes place within the soil mass where failure does not rely on variations of soil properties. Due to superimposition of rock layers and following sedimentation, clay minerals are repeatedly dehydrated, compacted and consolidated. Where water is absorbed and adsorbed once the load is removed causing water to flow between the platelets leading to increase in volume and consequent reduction of the bonding forces between particles. Hence in the course of landslide studies, clays are to be given due importance as their cohesion and shear strength values fall in the presence of water (Veder and Hilbert, 1980). There are two reasons that affect the loss of shear strength in clayey soils. First, is due to water absorption leading to swelling of the clays.

Second, is due to ion exchange, where loosely bonded clay minerals are restored by others. These two methods often interact, and hasten the process. If a stable water source is present, water will flow in and out of clayey and sandy soils cause movements. Under such conditions, the fine particles gets washed out and then the whole viscous mass slowly creeps downhill, even up to several millimetres a day, passing over constructions, roads, channels, etc. Comegna et al. (2007) is of the view that mudslides consist of softened clay that has water content much higher than the parent structure, and that 'flow' is the most widespread landslide type. The unusual constitution of materials structuring mudslides get highly simplified and softened.

In contrast to harder rocks, clay deposits are damaged by fine fissures though they are less affected by discontinuities. Slopes become unstable and slide down if the distance between fissures is restricted within few centimetres. (Ter-Stepanian, 1974; Gudehus et al., 1976; Blight, 1977) suggest that such slides of narrowly fissured clays take place as soon as the shear stresses go beyond the average shear strength of the material. In clay deposits, landslides are typically deep-seated rotational failures. Well consolidated clays generally have lots of small cracks and fissures, which sometimes form an interconnecting network throughout the material. Clays often posses well defined joints similar to that of hard rocks, which influence landslide. Discontinuities in clays facilitate water breach, which in turn softens up the mass leading to loss of cohesion and promotion of failure.

4.3 Structure

Structures approving for slope deformation are symbolized by a typical arrangement of rock complexes and system of faults, joints, etc. They are significant only if they occur along the slopes or ridges of local topography (Kandpal and Pant, 1995). Faults and joints are the two important structures that affect slope stability. Of these two, the more challenging one are the joints. Bedding planes, joints or faults are responsible for reducing the strength of rocks and their failure increases if the discontinuities are filled with clays and mixed with water, which acts as a lubricant. The seepage of water along joint and bedding planes is accountable for rockslides.

Important structures that encourages mass movements are joints, faults, fracture, etc. which play significant roles in most regions. These weak geological structures such as folds, bedding, cleavage, foliation, lineation, etc. have enhanced slope failure. Areas of closely spaced lineaments are predominantly prone to slope failure and severe erosion. Steep slopes characterize fault scarps or are related to hard rocks (Bartarya and Valdiya, 1989). For resolving slope stability, the intensity of fracturing, shearing, and the attitude of bedding or joints relative to slope geometry are significant measures. If the direction of joints favours potential slope failure, the effects of other criteria's becomes unimportant. The frequency of landslides is significant near thrust zones and decreases progressively as the distance from the thrust increases. In most cases, it is noted that the discontinuities dipping out of the slopes are accountable for surface instability. Mehrotra et al. (1993) deliberated that as the strike of the discontinuities approaches; the slope unevenness also increases proportionally. Geological discontinuities lessen rock mass strength with the significance in auxiliary instability of slopes (Donati and Turrini, 2002).

Sharma et al. (1996) opined that secondary discontinuities play a considerable role in causing slope failure, and that higher occurrence of discontinuities bring about more instability. In landslide studies, tectonic structures have been given very little significance, though it eminent that they are to blame for slope movement (Choubey and Lallenmawia, 1989). These structures play a very noteworthy nature in Nagaland, as landslide occurrences are high partly also because of large scale tectonic disturbances. Aier (2005) is of the opinion that abundant lineament as joints and faults in any area warrants severe erosion and slope failure. The degree of fracturing and shearing and the attitude of bedding or joint planes in relation to slope geometry are important methods for determination of slope stability. If the orientation of a joint plane favours potential slope failure, the effects of other properties becomes unimportant. Thong et al. (2006) showed the relationship between landslides and faults. Aier et al. (2011b), in its examination of the Merhülietsa slide, concluded that the slope material forming crumpled and weathered shale, have ultimately suffered shear failure due to heavy rainfall along the tectonically active Sarmah fault.

4.4 Groundwater condition

The study of the movement of subsurface water through rocks and the effect of subsurface flowing water on rocks, including their erosion, is very significant from the slope stability point of view. Rainfall is the principal source of groundwater where seepage into the subsurface is high during the monsoon. These waters percolate at different levels all along hill slopes during this phase. Hence, Sartori et al. (2003) affirms that groundwater trickles along diverse networks of joints work as triggering mechanisms of chemical alteration and water pressure.

Increase in water pressure in soils subjects to water absorption. The dissimilarity between the effective consolidation pressure and the pressure of water in contact with silty clay or clayey soils is the critical factor for water absorption and proportionate loss of strength. Veder and Hilbert (1980) is of the view that earth pressure remaining constant and hydrostatic pressure increasing the consolidated soil swells up. It is also eminent that an increase of water pressure in soils will lead to water absorption. Bartarya and Valdiya (1989) and Mathewson and Clary (1997) expressed that one of the triggering factor to decrease the shear resistance of landslides are alteration in underground water flow and prolong build-up of pore-water pressure. Piteau and Peckover (1989) opine that moisture also causes change in rocks. An increase in moisture content leads to swelling pressures in montmorillonite, which may occur in joints, either as infilling or as a product of alteration. These high swelling pressures and the low shear strength of montmorillonite can trigger rock falls, and in some instances, rock slides. A fluctuating water table can also add markedly to alteration and periodic changes in the mechanical properties of rocks. They have also stressed the fact of the controlling influences such as texture, stratigraphy and structure on aspects such as flow, permeability, recharge and storage capacity while giving consideration to environmental factors such as variations in climatic conditions, which result in periods of either high or low recharge or other distinction in groundwater conditions.

It is thus crucial to have a comprehensive knowledge of the hydrogeology of the region as pore-water pressure in joints is responsible for rock slides. Water influences the stability of an area as it enhances the pore-water pressure in joints (Terzaghi, 1962; Muller, 1964; Serafim, 1968). Varshney et al. (1987) states that as water flows all the way through the fissures it exerts lateral pressure on the rock mass, which is proportional to differential head. And as slide affected areas and slopes have unconsolidated overburden and disturbed bedrock it permits easy access to percolating waters to saturate the slope-forming material that causes instability.

The long-standing effect of earthquakes gradually modifies the pattern of drainage basins. Erosion and transport of landslide debris then contributes in formation of new alluvial fans, increasing the potential of debris flows or water flows over time (Keefer, 1999). Starkel (1972) states that wet clays act as lubricants if they exist in the middle of the regolith and bedrock. Presence of numerous cracks and joints in the vicinity results to higher infiltration. It decreases the shear strength of the rocks by dislodging air and building up pore pressure in the regolith. Hence in the regolith and in deeply jointed bedrocks the rate of infiltration from precipitation or surface runoff becomes quite high. Many landslides are caused due to unplanned and unscientific methods of development. Constructing and planning of highways without prior scientific study has taken its toll in slide-related areas. If roads are cut in places of adverse dips of beds and strikes, it is definite to affect the drainage along the slopes. In such areas, subsurface as well as surface waters should be efficiently drained off at various levels to direct water and to find a passage through the soil and rock mass.

4.5 Land use and land cover

Undesirable and unfavourable problem to the environment comprises of deforestation, soil erosion, slope modification, heavy constructions and other hostile human activities. Today, it is a given fact that natural forests and vegetation has been severely oppressed, bringing about a steady decline in the amount of their coverage. Deforestation brings about erosion and soil movement, but a matter of deliberation is its impact on creeping slopes (Gray, 1973). Crozier (1989) projected that, in forested and unpopulated slopes, slope angles and height appear to be beneath the critical limits for mass movement. Failure planes of landslides on weathered sedimentary rocks are commonly at some depth, below the root zone.

The constancy of hill slopes is directly or indirectly subjective of land use practices and land cover, because these factors control the rate of weathering and erosion of the underlying rock formations. Deforestation and the creation of arable land may allow significant water from rainfall to seep into the soil, while evaporation reduces. Deforestation has a particularly harmful effect if the remaining top soil is rapidly eroded by surface waters. Brown and Sheu (1975), concluded with an experimental observation, that elimination of huge weighty trees, which also reduces wind action on the vegetative cover, improves stability. Bishop and Stevens (1964) and Swanston (1974) confirm that in shallow-depth landslides detained to the root zone, the apparent cohesion of slope material are compacted with the steady decay of tree roots following deforestation. This increases the chance of slope failure.

Zaruba and Mencl (1969) affirm that vegetative-type conversion, concerning the changing of an area from trees and brush to a grass cover, may increase slope stability. Whereas, woodland plants help to enhance stability in the regolith by physical consolidation of roots and also by drying out of the surface layers. Several studies (Swanston and Dyrness, 1973; O'Loughlin, 1974; Burroughs and Thomas, 1977) exemplify the stabilizing effect of tree-root networks. The peak and residual shearing resistances were set up to improve two and four times respectively due to the roots. Lopez-Tello (1977) affirms that "safety factor" increases by 33 percent when 10 m high cut-slope in clay are enclosed with vegetation having a root density of 5000 Kg/ha. Wu and Swanston (1980) state that there was an exceptional increase in the incidence of landslides in shallow soils on hillside slopes of southeastern Alaska following timber harvest which clearly indicates that the loss of root strength and evapo-transpirational stress follows the cutting of the trees. (Greenway, 1987) is of the view that for improving stability of slopes, vegetated areas, chiefly dense with strong large root systems are of great assistance. For the firmness of slopes, vegetation is one essential means as it provides both hydrological and mechanical assistance. In contrast, slopes are easily destabilized in desolate areas and fallow land. Schuster (1997) is of the opinion that landslides controls topography, forests and grasslands and natural habitats. In such slides, a particular type of plant species, *Alprusnepalenses*,is found in great quantity (DGM, 1996).

On studying the impact of logging on landslide area at Clayoquot Sound, British Columbia, Jakob (2000) confirmed that the incidence of landslides in logged terrain is nine times higher than in uninterrupted forest. The rate of landslide shoots up exponentially within areas logged on a large watershed scale.

Shifting or slash-and-burn cultivation, locally known as Jhum cultivation, takes up an abrupt change in location of cropping areas. With increasing Jhum cycle period, accumulation of detrital matter amplifies, so also the water holding capacity and soil moisture content (Arunachalam, 1998). Frequent back-cutting for re-establishing road width added with poor drainage are responsible for the increase of landslides.

4.6 Rainfall

Several studies concluded that the great majority of the world's landslides are owed to intense rainfall. One important factor is the pressure exerted by the rainwater on the ground. Rainfall of high intensity normally leads to increased landslide activity. Pichler (1957), Barata (1969), Endo (1970), Vargas (1971) and Guidicini and Iwasa (1977) attempted to associate landslides and precipitation levels. During periods of very intense rainfall, abundant landslides generally occur, though the time sequence and amount of the annual rainfall differ deeply at any particular place. The affiliation between the amount of rainfall and frequency of landslide events was deliberated by Zaruba and Mencl (1982). They recognized that increase in the number of landslides correspond with periods of increased rainfall. The association between climate and landslides has lighted up interest levels of several researchers as rainfall is the main landslide-triggering factor in various regions in the world (Corominas, 2001). Areas with high mean annual rainfall are normally coupled with abundant recent landslides.

Extreme rainfalls often generate landslides, for a while with a considerable delay, directing to a decrease in the shearing strength of the soil due to swelling (Veder and Hilbert, 1980). Jworchan and Nutalaya (1994) directs that accumulating water on slopes due to rainfall, triggers landslides. Higher rainfall intensity is possibly required to cause landslides during the early months of the rainy seasons than the later months. Land sliding actually transpires more easily when the ground is saturated and the groundwater table is high. The progression of wet and dry spells during the rainy season is another important issue disturbing landslide activity. The dry period perhaps reduces the effects of the previous precipitation on the landslide-generating capacity of succeeding storms (Nilsen and Turner, 1975).

Debris build up on slopes is frequently unwarranted. Abundance of water during the monsoon merges with it causing debris flows. In totalling up to the annual rainfall, the recurrence interval of major storms, the yearly pattern of rainfall and longer-term changes in rainfall must be measured. The result of high rainfall on natural slopes may differ from slopes that have been comprehensively cut and filled, deforested or burnt. The common incidence of landslide in India drop in the class of rainfall-induced landslides, in areas especially restricted to periods of intense monsoon but that remain dry during the rest of the year (CRRI, 2000a).

Part of the natural procedure of hill slope erosion is the rainfall-induced landslides that offer in disastrous loss of life and widespread damage to property in mountainous, densely populated areas (Larsen, 2008). A prompting aspect that enhances landslides is infiltration from upslopes, finally saturating the soil around the toe of the flume (Beven and Kirkby, 1979; Montgomery and Dietrich, 1994; Acharya et al., 2006). Brand (1981) gives details of rain-induced method of collapse in unsaturated residual soils. Abdullah and Ali (1994) and Chenniah et al. (1994) asserts on the safety factor considering pore-water pressure for unsaturated residual soil slopes. Zhang et al. (2000) affirms that the system by which rainstorms can affect slope instability in the unsaturated zone in weathered rock encompasses percolation into the unsaturated part of a slope, resulting in rise of groundwater tables. Corominas et al. (2003) state that in slopes enclosed by pervious colluviums and weathered bedrock formations, high intensity and short-duration rainfall is able to trigger debris slides, debris flows and rock falls. High intensity rains frequently permit concentration and build-up of pore-water pressures that directs to slope failure. Campbell (1975) and Crozier (1999) submits that sufficient antecedent rainfall is essential to hold the regolith up to field capacity (the soil moisture beyond which gravity drainage will ensue), such that future rainfall may generate positive pore-pressure and prompt landslides. However, Emmanuel et al. (2004) opposes that landslides are not activated until about 860 mm of rain is experienced during the monsoon.

Another stardard decisive factor includes shallow and deep landslides. The performance of shallow and deep landslides is probably related to the infiltration processes (Iverson, 2000). Zezere et al. (2005) inveterated that shallow landslides are interrelated to intense rainfall periods ranging from 1 to 15 days, while deep slides to longer periods of less intense rain, lasting from 30 to 90 days. Dahal et al. (2008) conducted a meticulous study on the Himalayan slopes of Nepal and accomplished that shallow and highly mobile landslides are triggered by transitory pore-water pressure in reaction to intense monsoon rainfall and bedrock seepage. Tsai and Wang

(2010) accepted four means of rainfall patterns that include uniform, advanced, intermediate and delayed rainfall for experiment on controlling of rainfall pattern on shallow landslides due to indulgence of metric suction. Its conclusion is that rainfall pattern not only affects the result of shallow landslides but the pattern also affects the failure depth.

Heavy monsoon torrential rains relate to majority of the landslides experienced in Nagaland. The rainfall event does not vary drastically as the study area falls inside a small geographic division, and thus, the sequential likelihood is expected to be the same. Relentless rain storms are also frequently witnessed in Nagaland, with occasional cloudburst. Cloudbursts, mainly those happening well into the rainy season, or those consequently after prolonged wet spells, have displayed disaster and possibly been the main cause for some of the most destructive landslides in this area (Kemas et al., 2004; Thong et al., 2004; Aier, 2005). Sengupta et al. (2009) and Anbarasu et al. (2010) studied the process for commencement of the Lanta Khola landslide in the Sikkim Himalaya and concluded that there is a relationship between the amount of rainfall and slide movement. The area that was studied indicates that landslides are naturally affected most during the monsoon as it receives intensely high rainfall, usually after cloudbursts. Aier et al. (2009a) arranged a geotechnical assessment of the Mehrülietsa slide along NH 39 at Kohima and concluded that heavy rainfall was the main cause to generate the landslide.

4.7 Seismicity

Permanent and disastrous deformation is caused during earthquakes. Such earth vibrations weaken slopes, thereby causing collapse by plummeting the factor of safety of slope material. Factors concerned includes the intensity and duration of shaking, the type of slope, slope geometry; geo-technical factors like shear strength, deformation response, local geological details and existing pore-water pressures due to seepage, impounded water or other like conditions. The role of seismicity should be calculated from historic landslide events (Thigale, 1999).Many outsized landslides have been caused by earthquakes (Schuster and Highland, 2001). As Malamud et al. (2004) puts it, that landslide incidences are generally associated with activation of an earthquake, a large storm, rapid snow melt, or a volcanic eruption. Pointers such as ground velocity, knowledge of past earthquake events and the length of shaking are good indicators of landslide susceptibility under seismic conditions. The critical steepening of a slope is also an important factor in determine the seismic safety of a slope.

Keefer (1984) and Rodriguez et al. (1999) stated that landslides may trigger due to earthquakes of magnitude 4 or larger. Sassa (1996) opines that seismic landslide incidence is strongly focused to the nearness of the fault rupture. Later, shared by Wen et al. (2004) says that the position of most of large landslides is very close to major fault zones. Dadson et al. (2004) made study on the co- and post-seismic geomorphic impact of the 1999 Chi-Chi event in Taiwan. And found out that in addition to the 20,000 landslides immediately triggered by the earthquake, they found that co-seismic waning of substrate material had caused bigger landsliding during succeeding typhoons. Afterward, they acknowledged that majority of the co-seismically shaped landslide material got elated towards the rivers, and observed an increased sediment concentration all through the storms after the earthquake. Papathanassiou et al. (2005) states that most distinguishing co-seismic effects were typical ground failures like rock falls, soil liquefaction, ground cracks and slope failure. Havenith and Bourdeau (2010) accomplished that the giant rockslides were set in motion by large magnitude seismic events ($M \geq 7$) in the central Asian mountainous regions; loose earth-flows may be generated by smaller earthquakes, or even by other climatic factors alone.

After the Kashmir earthquake in 2005, Petley et al. (2006) cautiously noted that close to the fault rupture, there was a high incidence of landslides generated by the earthquake, and that the allocation of these landslides materializes to be very asymmetric, with the majority of the landslides being positioned on the hanging wall on the northeastern side of the fault. Basing on the same event, Sato et al. (2007) further confirmed that more than one third of the landslides happened within 1 km from the active fault.

Gurung et al. (2011) implies that from the stability studies of the Laprak Landslide of Nepal a dry season earthquake does not produce future movement but a wet season earthquake can magnify the effects of high pore-water pressure and produce sliding with even low factors of safety.

Assessing the geographical situation of Nagaland, Nagaland falls beneath the Zone-V of the seismic zonation map of India with an expected tremor magnitude greater than 8. More than 40 earthquakes of magnitudes greater than 6 on the Richter scale have been evidenced in the last century in the NE region. Two earthquakes which occurred in Shillong (1897) and Assam (1950) in the north-eastern region, measured a magnitude greater than 8. Continual earthquakes in the north-eastern region caused by sporadic tectonic stress release, signifies a pattern of orogenic movements still in progress (Verma, 1985). Froehlich et al. (1992) upholds that joints of high density in rocks are most probably associated with high seismicity of any region which also affirms large scale mass wasting. Hence, it is of utmost importance to take seismicity into consideration while studying and considering landslides. Appropriate records and documents describing landslide events of past earthquakes in this region are still scarce. To unravel its dynamics in this region needs methodical assessment and answers from past evidences and recent incidences.

CHAPTER 5

THEMATIC MAPPING

INTRODUCTION

The targeted study begins from Kohima, the state capital of Nagaland and extends towards Mao, a part of Manipur. The stretch covers a distance of about 32km and is 18 sq km (approx) in area. Tangible investigation on the subject based on Quantitative data of geo-environmental factors such as slope, relative relief, lithology, structure, groundwater and land use / land cover are given in tables 5.1a and 5.1b.

5.1 Slope angle

It has been recognized that five different categories of slopes are prominent in the study area (Fig. 5.1a). They comprise of very gentle, gentle, moderately steep, steep, and very steep slopes. Very gentle slopes cover an area of 0.48sq km, which outlines2.65% of the total area. Gentle slopes occupy 9.88sq km and represent 55.67% of the area. Moderately steep slopes cover 6.49sq km and represent 34.97%.Steep and very steep slopes cover 1.18 and 0.07 sq km respectively, which is 6.37% and 0.34% respectively. Ratings for different categories of slope are assigned (Table 5.1b). Table 5.2 shows the frequency of landslides on the various slope categories. Further, the pie chart indicates slope angle distribution (Fig. 5.1b).

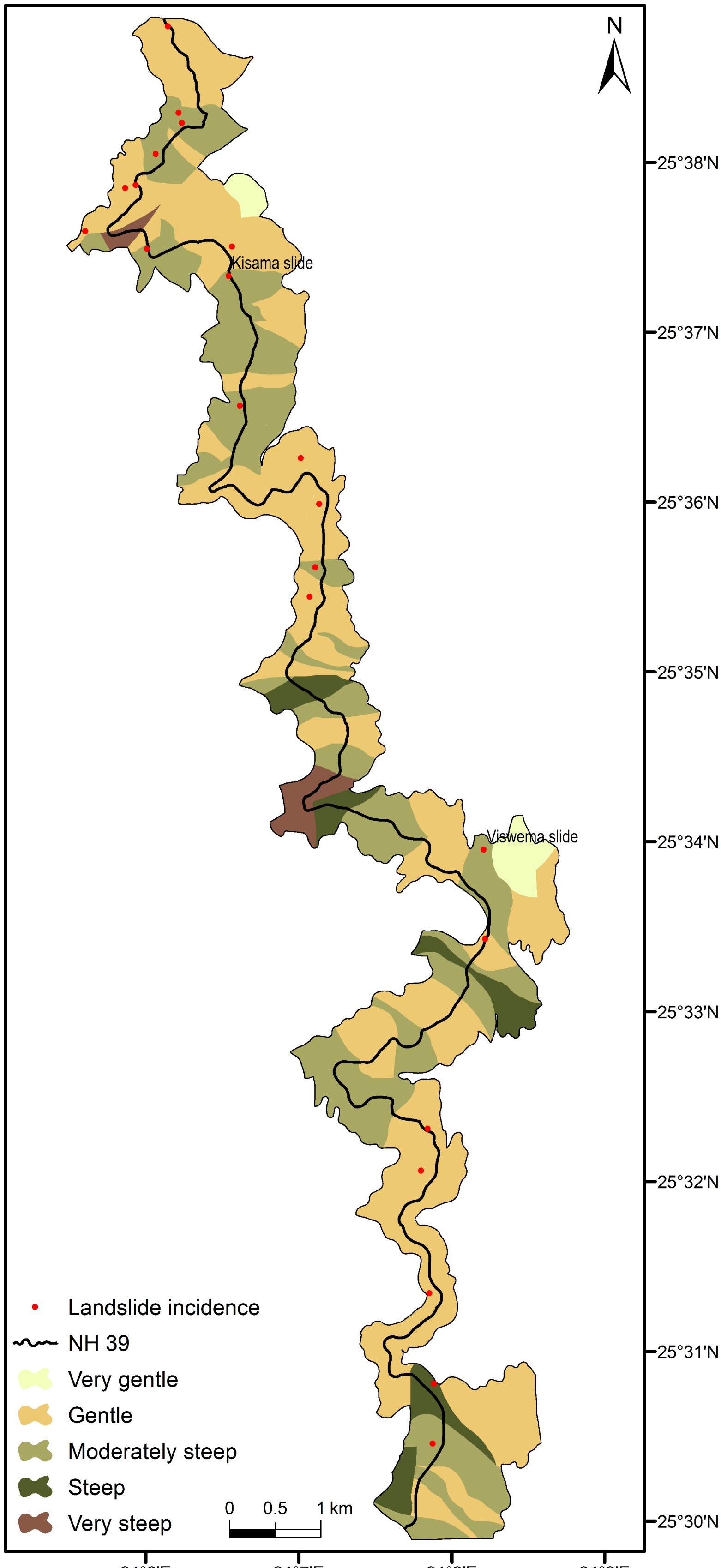


Fig.5.1a Slope Morphometric Map

Table 5.1.a Observations

Facet No	Slope Categories	Relative Relief	Lithology	Groundwater Condition	Land Use / Land Cover
1	Gentle	Low	Loose debris	Flowing	Populated land
2	Gentle	Low	Crumpled shale	Dripping	Populated land
3	Gentle	Low	Loose debris	Wet	Sparse vegetation
4	Gentle	Low	Crumpled shale	Wet	Populated land
5	Gentle	Low	Crumpled shale	Damp	Populated land
6	Gentle	Low	Loose debris	Wet	Populated land
7	Moderately steep	Moderate	Loose debris	Wet	Populated land
8	Moderately steep	Moderate	Loose debris	Dripping	Sparse vegetation
9	Moderately steep	Moderate	Loose debris	Wet	Sparse vegetation
10	Gentle	Low	Weathered shale	Wet	Terrace cultivation
11	Moderately steep	Moderate	Weathered shale	Wet	Terrace cultivation
12	Moderately steep	Moderate	Weathered shale	Wet	Terrace cultivation
13	Moderately steep	Moderate	Weathered shale	Dripping	Terrace cultivation
14	Gentle	Low	Weathered shale	Flowing	Terrace cultivation
15	Gentle	Moderate	Weathered shale	Dripping	Terrace cultivation

16	Gentle	Moderate	Shale with minor sandstone	Dripping	Sparse vegetation
17	Gentle	Moderate	Shale with minor sandstone	Damp	Moderate vegetation
18	Moderately steep	Moderate	Shale with minor sandstone	Flowing	Dense vegetation
19	Very steep	Moderate	Sandstone with minor shale	Flowing	Moderate vegetation
20	Gentle	Moderate	Shale with minor sandstone	Damp	Moderate vegetation
21	Moderately steep	Moderate	Loose debris	Dripping	Sparse vegetation
22	Moderately steep	Moderate	Shale with minor sandstone	Dripping	Sparse vegetation
23	Moderately steep	Moderate	Loose debris	Damp	Moderate vegetation
24	Gentle	Moderate	Partially loose debris	Damp	Moderate vegetation
25	Gentle	Moderate	Weathered shale	Wet	Terrace cultivation
26	Gentle	Low	Weathered shale	Wet	Terrace cultivation
27	Gentle	Moderate	Loose debris	Wet	Sparse vegetation
28	Gentle	Moderate	Partially loose debris	Dripping	Populated land
29	Gentle	Moderate	Partially weathered shale	Wet	Populated land
30	Very gentle	Low	Crumpled shale	Wet	Populated land
31	Very gentle	Low	Crumpled shale	Wet	Populated land
32	Gentle	Moderate	Crumpled shale	Wet	Populated land
33	Gentle	Low	Weathered shale	Dripping	Terrace cultivation
34	Moderately steep	Moderate	Weathered shale	Dripping	Sparse vegetation

35	Moderately steep	Moderate	Weathered shale	Dripping	Terrace cultivation
36	Moderately steep	Moderate	Weathered shale	Dripping	Terrace cultivation
37	Gentle	Low	Weathered shale	Dripping	Terrace cultivation
38	Gentle	Low	Weathered shale	Dripping	Terrace cultivation
39	Gentle	Moderate	Weathered shale	Dripping	Terrace cultivation
40	Moderately steep	Moderate	Partially weathered shale	Damp	Sparse vegetation
41	Moderately steep	Moderate	Crumpled shale	Damp	Populated land
42	Moderately steep	Moderate	Sandstone with minor shale	Damp	Sparse vegetation
43	Moderately steep	Moderate	Weathered shale	Damp	Sparse vegetation
44	Gentle	Moderate	Crumpled shale	Damp	Moderate vegetation
45	Moderately steep	Moderate	Crumpled shale	Damp	Moderate vegetation
46	Moderately steep	Moderate	Loose debris	Damp	Sparse vegetation
47	Moderately steep	Moderate	Crumpled shale	Damp	Populated land
48	Moderately steep	Moderate	Crumpled shale	Damp	Populated land
49	Gentle	Low	Crumpled shale	Damp	Populated land
50	Gentle	Low	Crumpled shale	Damp	Populated land
51	Moderately steep	Moderate	Partially weathered shale	Damp	Populated land
52	Moderately steep	Moderate	Partially weathered shale	Damp	Populated land
53	Moderately steep	Moderate	Weathered shale	Wet	Terrace cultivation

54	Gentle	Moderate	Weathered shale	Dripping	Terrace cultivation
55	Gentle	Low	Shale with minor sandstone	Flowing	Moderate vegetation
56	Gentle	Moderate	Partially weathered shale	Dripping	Sparse vegetation
57	Gentle	Moderate	Crumpled shale	Wet	Moderate vegetation
58	Gentle	Low	Crumpled shale	Damp	Populated land
59	Gentle	Low	Crumpled shale	Damp	Populated land
60	Gentle	Moderate	Crumpled shale	Damp	Populated land
61	Gentle	Low	Loose debris	Damp	Sparse vegetation
62	Gentle	Low	Shale with minor sandstone	Damp	Sparse vegetation
63	Gentle	Moderate	Sandstone with minor shale	Damp	Populated land
64	Gentle	Moderate	Partially loose debris	Dripping	Populated land
65	Gentle	Low	Crumpled shale	Wet	Populated land
66	Gentle	Moderate	Sandstone with minor shale	Damp	Populated land
67	Moderately steep	Moderate	Crumpled shale	Dripping	Populated land
68	Moderately steep	Moderate	Crumpled shale	Damp	Populated land
69	Gentle	Moderate	Partially weathered shale	Dripping	Sparse vegetation
70	Gentle	Low	Partially weathered shale	Wet	Sparse vegetation
71	Gentle	Moderate	Weathered shale	Wet	Terrace cultivation
72	Moderately steep	Moderate	Weathered shale	Wet	Terrace cultivation

73	Gentle	Low	Weathered shale	Wet	Terrace cultivation
74	Moderately steep	Moderate	Weathered shale	Wet	Terrace cultivation
75	Gentle	Low	Crumpled shale	Flowing	Populated land
76	Moderately steep	Moderate	Partially weathered shale	Wet	Dense vegetation
77	Steep	Moderate	Partially weathered shale	Wet	Dense vegetation
78	Steep	Moderate	Sandstone with minor shale	Damp	Moderate vegetation
79	Moderately steep	Moderate	Sandstone with minor shale	Damp	Moderate vegetation
80	Moderately steep	Moderate	Shale with minor sandstone	Wet	Moderate vegetation
81	Gentle	Low	Shale with minor sandstone	Wet	Moderate vegetation
82	Gentle	Moderate	Partially loose debris	Damp	Populated land
83	Moderately steep	Moderate	Partially loose debris	Damp	Populated land
84	Moderately steep	Moderate	Sandstone with minor shale	Damp	Sparse vegetation
85	Very steep	Moderate	Sandstone with minor shale	Wet	Sparse vegetation
86	Very steep	Moderate	Partially loose debris	Flowing	Moderate vegetation
87	Very steep	Moderate	Partially loose debris	Dripping	Moderate vegetation
88	Steep	Moderate	Sandstone with minor shale	Wet	Moderate vegetation
89	Moderately steep	Moderate	Loose debris	Damp	Moderate vegetation
90	Moderately steep	Moderate	Sandstone with minor shale	Damp	Moderate vegetation
91	Moderately steep	Moderate	Sandstone with minor shale	Damp	Moderate vegetation

92	Moderately steep	Moderate	Partially weathered shale	Damp	Moderate vegetation
93	Gentle	Low	Weathered shale	Damp	Terrace cultivation
94	Gentle	Low	Sandstone with minor shale	Damp	Populated land
95	Gentle	Low	Partially loose debris	Dripping	Populated land
96	Moderately steep	Moderate	Loose debris	Dripping	Sparse vegetation
97	Moderately steep	Moderate	Loose debris	Dripping	Sparse vegetation
98	Very gentle	Low	Weathered shale	Dripping	Terrace cultivation
99	Very gentle	Low	Weathered shale	Dripping	Terrace cultivation
100	Very gentle	Low	Weathered shale	Dripping	Terrace cultivation
101	Gentle	Low	Partially loose debris	Damp	Populated land
102	Gentle	Low	Partially loose debris	Damp	Populated land
103	Gentle	Low	Partially loose debris	Damp	Populated land
104	Gentle	Low	Partially loose debris	Damp	Populated land
105	Gentle	Low	Loose debris	Dripping	Sparse vegetation
106	Moderately steep	Moderate	Weathered shale	Dripping	Sparse vegetation
107	Steep	Moderate	Sandstone with minor shale	Damp	Sparse vegetation
108	Moderately steep	Moderate	Partially weathered shale	Dripping	Moderate vegetation
109	Gentle	Moderate	Crumpled shale	Dripping	Moderate vegetation
110	Gentle	Moderate	Crumpled shale	Dripping	Moderate vegetation

111	Gentle	Low	Crumpled shale	Dripping	Moderate vegetation
112	Moderately steep	Moderate	Crumpled shale	Dripping	Moderate vegetation
113	Moderately steep	Moderate	Partially loose debris	Damp	Moderate vegetation
114	Gentle	Moderate	Partially loose debris	Damp	Moderate vegetation
115	Gentle	Moderate	Sandstone with minor shale	Wet	Moderate vegetation
116	Gentle	Moderate	Partially loose debris	Damp	Moderate vegetation
117	Moderately steep	Moderate	Partially loose debris	Flowing	Moderate vegetation
118	Moderately steep	Moderate	Partially loose debris	Damp	Dense vegetation
119	Moderately steep	Moderate	Crumpled shale	Damp	Dense vegetation
120	Moderately steep	Moderate	Sandstone with minor shale	Damp	Moderate vegetation
121	Moderately steep	Moderate	Partially loose debris	Wet	Moderate vegetation
122	Moderately steep	Moderate	Partially loose debris	Damp	Moderate vegetation
123	Moderately steep	Moderate	Crumpled shale	Damp	Moderate vegetation
124	Gentle	Moderate	Crumpled shale	Damp	Moderate vegetation
125	Gentle	Low	Weathered shale	Dripping	Terrace cultivation
126	Gentle	Low	Partially loose debris	Damp	Populated land
127	Gentle	Low	Partially loose debris	Damp	Populated land
128	Gentle	Low	Partially loose debris	Dripping	Moderate vegetation
129	Gentle	Moderate	Partially loose debris	Damp	Sparse vegetation

130	Gentle	Moderate	Partially loose debris	Damp	Sparse vegetation
131	Gentle	Moderate	Partially loose debris	Damp	Sparse vegetation
132	Gentle	Low	Partially loose debris	Dripping	Sparse vegetation
133	Gentle	Low	Partially loose debris	Dripping	Moderate vegetation
134	Gentle	Low	Weathered shale	Dripping	Terrace cultivation
135	Gentle	Low	Partially loose debris	Wet	Sparse vegetation
136	Gentle	Low	Partially loose debris	Wet	Sparse vegetation
137	Gentle	Low	Partially loose debris	Wet	Sparse vegetation
138	Gentle	Moderate	Partially loose debris	Wet	Sparse vegetation
139	Steep	Moderate	Partially loose debris	Damp	Populated land
140	Gentle	Low	Partially loose debris	Damp	Populated land
141	Gentle	Low	Partially loose debris	Damp	Populated land
142	Gentle	Low	Partially loose debris	Damp	Populated land
143	Gentle	Low	Partially loose debris	Wet	Populated land
144	Moderately steep	Moderate	Partially loose debris	Damp	Populated land
145	Moderately steep	Moderate	Loose debris	Wet	Sparse vegetation
146	Moderately steep	Moderate	Loose debris	Wet	Sparse vegetation
147	Steep	Moderate	Loose debris	Damp	Sparse vegetation
148	Gentle	Moderate	Partially loose debris	Wet	Populated land

149	Steep	Moderate	Loose debris	Damp	Sparse vegetation
150	Moderately steep	Moderate	Partially loose debris	Wet	Populated land
151	Steep	Moderate	Partially loose debris	Wet	Populated land
152	Gentle	Low	Partially loose debris	Dripping	Populated land
153	Moderately steep	Moderate	Partially loose debris	Dripping	Populated land

Table 5.1.b. LHEF and TEHD

Facet No	Slope (2.0)	Relative relief (1.0)	Lithology (2.5)	Structure (2.00)	Groundwater (1.0)	Lu/Lc (1.50)	TEHD (10.0)	LHZ
1	0.8	0.3	2.5	2.00	1.0	0.65	7.25	VHH
2	0.8	0.3	2.0	0.85	0.8	0.65	5.40	MH
3	0.8	0.3	2.5	0.65	0.5	1.20	5.95	HH
4	0.8	0.3	2.0	0.85	0.5	0.65	5.10	MH
5	0.8	0.3	2.0	0.85	0.2	0.65	4.80	MH
6	0.8	0.3	2.5	0.85	0.5	0.65	5.60	HH
7	1.2	0.6	2.5	0.85	0.5	0.65	6.30	HH
8	1.2	0.6	2.5	2.00	0.8	1.20	8.30	VHH
9	1.2	0.6	2.5	0.65	0.5	1.20	6.65	HH
10	0.8	0.3	2.5	0.65	0.5	1.50	6.25	HH
11	1.2	0.6	2.5	0.65	0.5	1.50	6.95	VHH
12	1.2	0.6	2.5	0.85	0.5	1.50	7.15	VHH
13	1.2	0.6	2.5	0.85	0.8	1.50	7.45	VHH
14	0.8	0.3	2.5	0.85	1.0	1.50	6.95	VHH
15	0.8	0.6	2.5	0.65	0.8	1.50	6.85	VHH
16	0.8	0.6	1.5	1.85	0.8	1.20	6.75	HH
17	0.8	0.6	1.5	1.85	0.2	1.00	5.95	HH
18	1.2	0.6	1.5	2.00	1.0	0.80	7.10	VHH
19	2.0	0.6	0.5	1.75	1.0	1.00	6.85	VHH
20	0.8	0.6	1.5	1.30	0.2	1.00	5.40	MH
21	1.2	0.6	2.5	0.85	0.8	1.20	7.15	VHH
22	1.2	0.6	1.5	1.40	0.8	1.20	6.70	HH
23	1.2	0.6	2.5	0.85	0.2	1.00	6.35	HH
24	0.8	0.6	2.5	0.85	0.2	1.00	5.95	HH
25	0.8	0.6	2.5	0.85	0.5	1.50	6.75	HH
26	0.8	0.3	2.5	0.85	0.5	1.50	6.45	HH
27	0.8	0.6	2.5	0.85	0.5	1.20	6.45	HH

28	0.8	0.6	2.5	0.85	0.8	0.65	6.20	HH
29	0.8	0.6	2.0	0.85	0.5	0.65	5.40	MH
30	0.5	0.3	2.0	0.85	0.2	0.65	4.50	LH
31	0.5	0.3	2.0	0.85	0.2	0.65	4.50	LH
32	0.8	0.6	2.0	0.65	0.5	0.65	5.20	MH
33	0.8	0.3	2.5	0.85	0.8	1.50	6.75	HH
34	1.2	0.6	2.5	0.85	0.8	1.20	7.15	VHH
35	1.2	0.6	2.5	0.85	0.8	1.50	7.45	VHH
36	1.2	0.6	2.5	0.85	0.8	1.50	7.45	VHH
37	0.8	0.3	2.5	0.85	0.8	1.50	6.75	HH
38	0.8	0.3	2.5	0.85	0.8	1.50	6.75	HH
39	0.8	0.6	2.5	0.85	0.8	1.50	7.05	VHH
40	1.2	0.3	2.0	2.00	0.2	1.20	6.90	VHH
41	1.2	0.6	2.0	2.00	0.2	0.65	6.65	HH
42	1.2	0.6	0.5	1.85	0.2	1.20	5.55	HH
43	1.2	0.6	2.5	1.30	0.2	1.20	7.00	VHH
44	0.8	0.6	2.0	1.30	0.2	1.00	5.90	HH
45	1.2	0.6	2.0	1.30	0.2	1.00	6.30	HH
46	1.2	0.6	2.5	1.30	0.2	1.20	7.00	VHH
47	1.2	0.6	2.0	0.85	0.2	0.65	5.50	HH
48	1.2	0.6	2.0	0.85	0.2	0.65	5.50	HH
49	0.8	0.3	2.0	0.85	0.2	0.65	4.80	MH
50	0.8	0.3	2.0	0.85	0.2	0.65	4.80	MH
51	1.2	0.6	2.0	0.85	0.2	0.65	5.50	HH
52	1.2	0.6	2.0	0.85	0.2	0.65	5.50	HH
53	1.2	0.6	2.5	0.85	0.5	1.50	7.15	VHH
54	0.8	0.6	2.5	0.65	0.8	1.50	6.85	VHH
55	0.8	0.3	1.5	1.95	1.0	1.00	6.55	HH
56	0.8	0.6	2.0	0.85	0.8	1.20	6.25	HH
57	0.8	0.6	2.0	0.85	0.5	1.00	5.75	HH
58	0.8	0.3	2.0	0.65	0.2	0.65	4.60	MH
59	0.8	0.3	2.0	0.65	0.2	0.65	4.60	MH

60	0.8	0.6	2.0	0.65	0.2	0.65	4.90	MH
61	0.8	0.3	2.5	0.85	0.2	1.20	5.85	HH
62	0.8	0.3	2.0	1.95	0.2	1.20	6.45	HH
63	0.8	0.6	0.5	1.95	0.2	0.65	4.70	MH
64	0.8	0.6	2.5	2.00	0.8	0.65	7.35	VHH
65	0.8	0.3	2.0	1.30	0.5	0.65	5.55	HH
66	0.8	0.6	0.5	1.50	0.2	0.65	4.25	LH
67	1.2	0.6	2.0	1.30	0.8	0.65	6.55	HH
68	1.2	0.6	2.0	1.30	0.2	0.65	5.95	HH
69	0.8	0.6	2.0	2.00	0.8	1.20	7.40	VHH
70	0.8	0.3	2.0	1.30	0.5	1.20	6.10	HH
71	0.8	0.6	2.5	0.85	0.5	1.50	6.75	HH
72	1.2	0.6	2.5	0.85	0.5	1.50	7.15	VHH
73	0.8	0.3	2.5	0.85	0.5	1.50	6.45	HH
74	1.2	0.6	2.5	0.85	0.5	1.50	7.15	VHH
75	0.8	0.3	2.0	1.30	1.0	0.65	6.05	HH
76	1.2	0.6	2.0	0.65	0.5	0.80	5.75	HH
77	1.7	0.6	2.0	0.65	0.5	0.80	6.25	HH
78	1.7	0.6	0.5	1.05	0.2	1.00	5.05	MH
79	1.2	0.6	0.5	1.20	0.2	1.00	4.70	MH
80	1.2	0.6	1.5	1.20	0.5	1.00	6.00	HH
81	0.8	0.3	1.5	1.05	0.5	1.00	5.15	MH
82	0.8	0.6	2.5	0.65	0.2	0.65	5.40	MH
83	1.2	0.6	2.5	0.65	0.2	1.20	6.35	HH
84	1.2	0.6	0.5	1.85	0.2	1.20	5.55	HH
85	2.0	0.6	0.5	1.85	0.5	1.20	6.65	HH
86	2.0	0.6	2.5	0.85	1.0	1.00	7.95	VHH
87	2.0	0.6	2.5	0.85	0.8	1.00	7.75	VHH
88	1.7	0.6	0.5	1.95	0.5	1.00	6.25	HH
89	1.2	0.6	2.5	0.85	0.2	1.00	6.35	HH
90	1.2	0.6	0.5	2.00	0.2	1.00	5.50	HH
91	1.2	0.6	0.5	1.85	0.2	1.00	5.35	MH

92	1.2	0.6	2.0	1.95	0.2	1.00	6.95	VHH
93	0.8	0.3	2.5	0.85	0.2	1.50	6.15	HH
94	0.8	0.3	0.5	1.30	0.2	0.65	3.75	LH
95	0.8	0.3	2.5	1.00	0.8	0.65	6.05	HH
96	1.2	0.6	2.5	2.00	0.8	1.20	8.30	VHH
97	1.2	0.3	2.5	2.00	0.8	1.20	8.00	VHH
98	0.5	0.3	2.5	1.30	0.8	1.50	6.90	VHH
99	0.5	0.3	2.5	1.30	0.8	1.50	6.90	VHH
100	0.5	0.3	2.5	1.30	0.8	1.50	6.90	VHH
101	0.8	0.3	2.5	1.30	0.2	0.65	5.75	HH
102	0.8	0.3	2.5	1.30	0.2	0.65	5.75	HH
103	0.8	0.3	2.5	1.30	0.2	0.65	5.75	HH
104	0.8	0.3	2.5	1.30	0.2	0.65	5.75	HH
105	0.8	0.3	2.5	1.30	0.8	1.20	6.90	VHH
106	1.2	0.6	2.5	1.30	0.8	1.20	7.60	VHH
107	1.7	0.6	0.5	1.05	0.2	1.20	5.25	MH
108	1.2	0.6	2.0	1.30	0.8	1.00	6.90	VHH
109	0.8	0.6	2.0	1.30	0.8	1.00	6.50	HH
110	0.8	0.6	2.0	1.30	0.8	1.00	6.50	HH
111	0.8	0.3	2.0	1.30	0.8	1.00	6.20	HH
112	1.2	0.6	2.0	1.75	0.8	1.00	7.35	VHH
113	1.2	0.6	2.5	1.30	0.2	1.00	6.80	VHH
114	0.8	0.6	2.5	1.30	0.2	1.00	6.40	HH
115	0.8	0.6	0.5	1.85	0.5	1.00	5.25	MH
116	0.8	0.6	2.5	1.30	0.2	1.00	6.40	HH
117	1.2	0.6	2.5	1.60	1.0	1.00	7.90	VHH
118	1.2	0.6	2.5	0.85	0.2	0.80	6.15	HH
119	1.2	0.6	2.0	0.85	0.2	0.80	5.65	HH
120	1.2	0.6	0.5	1.85	0.2	1.00	5.35	MH
121	1.2	0.6	2.5	0.85	0.5	1.00	6.65	HH
122	1.2	0.6	2.5	0.85	0.2	1.00	6.35	HH
123	1.2	0.6	2.0	0.85	0.2	1.00	5.85	HH

124	0.8	0.6	2.0	0.85	0.2	1.00	5.45	HH
125	0.8	0.3	2.5	0.85	0.8	1.50	6.75	HH
126	0.8	0.3	2.5	1.70	0.2	0.65	6.15	HH
127	0.8	0.3	2.5	0.85	0.2	0.65	5.30	MH
128	0.8	0.3	2.5	0.85	0.8	1.00	6.25	HH
129	0.8	0.6	2.5	1.30	0.2	1.20	6.60	HH
130	0.8	0.6	2.5	1.30	0.2	1.20	6.60	HH
131	0.8	0.6	2.5	1.30	0.2	1.20	6.60	HH
132	0.8	0.3	2.5	1.30	0.8	1.20	6.90	VHH
133	0.8	0.3	2.5	1.30	0.8	1.00	6.70	HH
134	0.8	0.3	2.5	0.85	0.8	1.50	6.75	HH
135	0.8	0.3	2.5	2.00	0.5	1.20	7.30	VHH
136	0.8	0.3	2.5	2.00	0.5	1.20	7.30	VHH
137	0.8	0.3	2.5	2.00	0.5	1.20	7.30	VHH
138	0.8	0.6	2.5	1.85	0.5	1.20	7.45	VHH
139	1.7	0.6	2.5	1.30	0.2	0.65	6.95	VHH
140	0.8	0.3	2.5	1.30	0.2	0.65	5.75	HH
141	0.8	0.3	2.5	1.30	0.2	0.65	5.75	HH
142	0.8	0.3	2.5	1.30	0.2	0.65	5.75	HH
143	0.8	0.3	2.5	1.30	0.5	0.65	6.05	HH
144	1.2	0.6	2.5	1.30	0.2	0.65	6.45	HH
145	1.2	0.6	2.5	1.30	0.5	1.20	7.30	VHH
146	1.2	0.6	2.5	1.30	0.5	1.20	7.30	VHH
147	1.7	0.6	2.5	1.30	0.2	1.20	7.50	VHH
148	0.8	0.6	2.5	1.30	0.5	0.65	6.35	HH
149	1.7	0.6	2.5	1.30	0.2	1.20	7.50	VHH
150	1.2	0.6	2.5	1.30	0.5	0.65	6.75	HH
151	1.7	0.6	2.5	1.30	0.5	0.65	7.25	VHH
152	0.8	0.3	2.5	1.30	0.8	0.65	6.35	HH
153	1.2	0.6	2.5	2.00	0.8	0.65	7.75	VHH

Table 5.2 Frequency of landslide incidences on slope

Category	Area		Landslide		Frequency
	km^2	**%**	**No**	**%**	**No/km^2**
Very gentle	0.48	2.65	-	-	-
Gentle	9.88	55.67	12	54.54	1.22
Moderately steep	6.49	34.97	9	40.91	1.45
Steep	1.18	6.37	1	4.55	0.88
Very steep	0.07	0.34	-	-	-

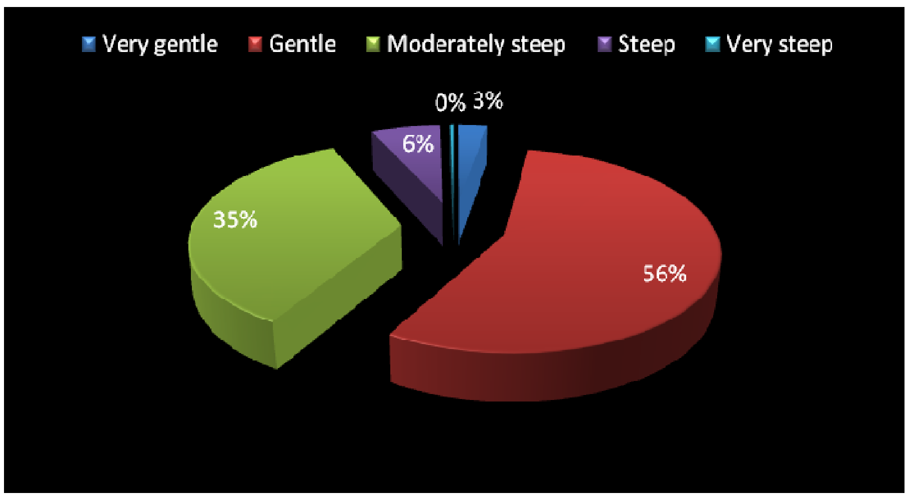


Fig. 5.1b Distribution of slopes

5.2 Relative relief

According to the above figure (Fig. 5.2a), three categories of relief are noted in this area. It includes low, medium and high relief (Table 5.3). While the areas of low relief occupy 6.36 sq km; and medium relief occupies 11.74 sq km,there is no high relief noted in the area. Low relief is noted in 35.14% of this area and medium relief in 64.86%. Ratings for the relative relief of the area are given in table 5.1b. The pie chart shows the distribution of the categories of relative relief (Fig. 5.2b).

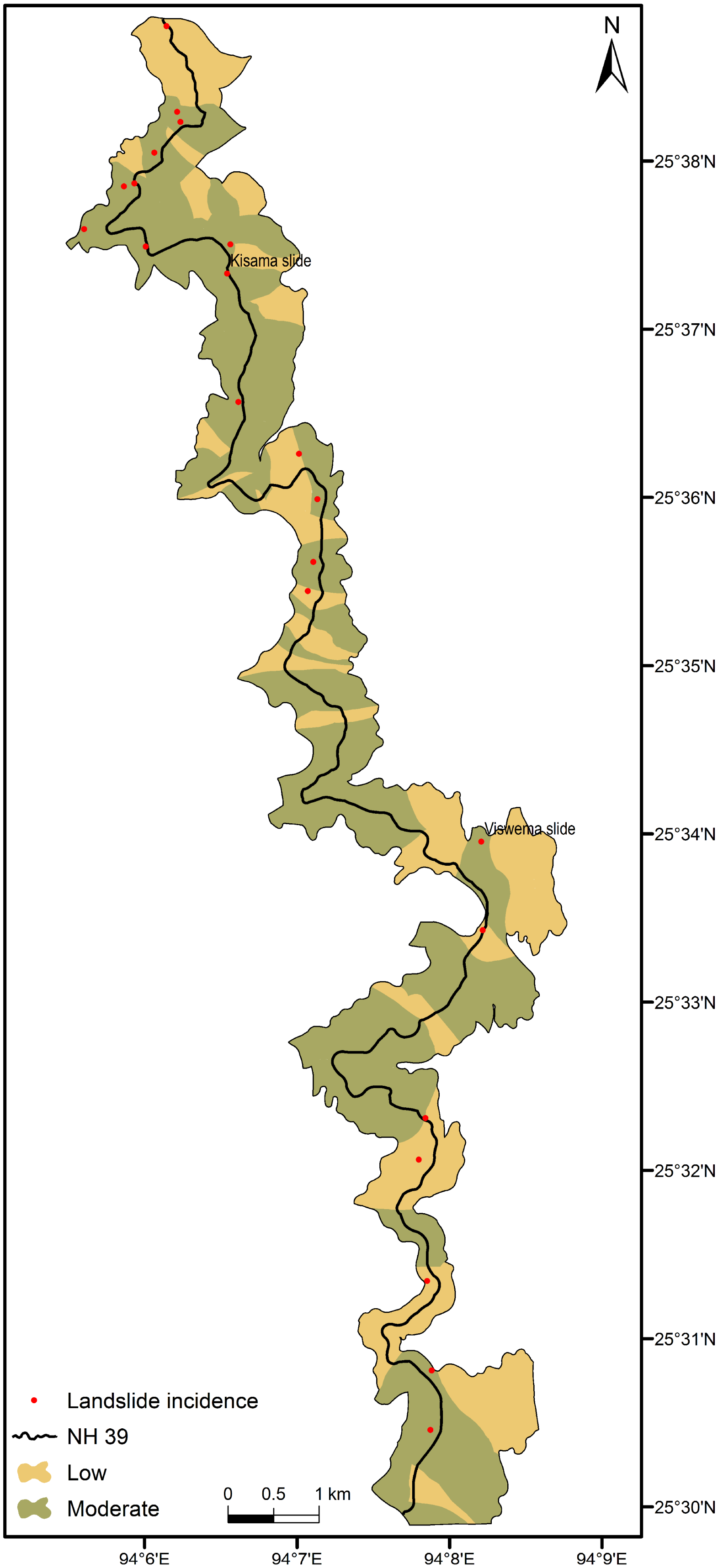


Fig.5.2a. Relative Relief Map

Table 5.3 Relative relief and area distribution

Category	Area		Landslide		Frequency
	km^2	%	No	%	No/km^2
Low relief	6.36	35.14	7	31.82	1.1
Medium relief	11.74	64.86	15	68.18	1.28

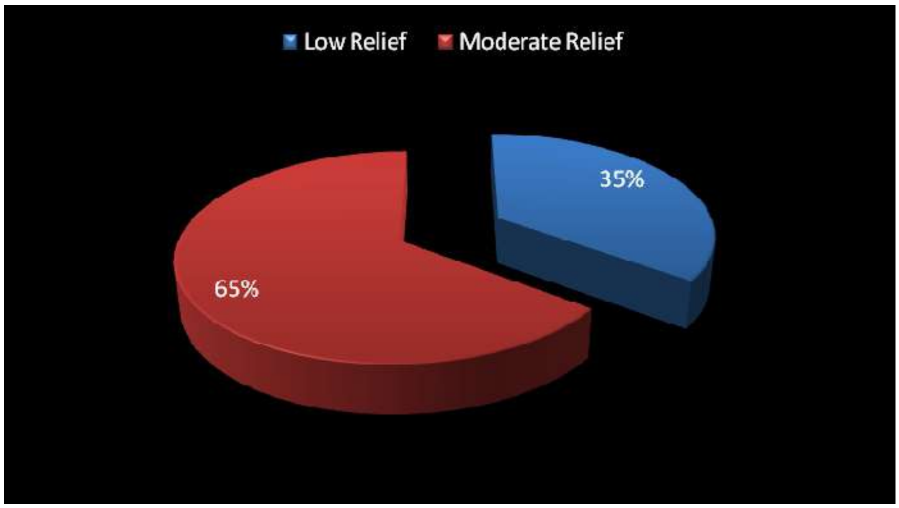


Fig. 5.2b Distribution of relative relief

5.3 Lithology

Seven different classes of litho-units are noted in this area (Fig. 5.3a); and the ratings for the various litho-units are given in table 5.1b. The first class is represented by sandstone with minor shale which occupies an area of 2.13sq km and which is 11.77% of the total area. The second class consists of shale with minor sandstone which occupies 1.00sq km, which is 5.52% of the area. The third class consists of crumpled shale which occupies 2.96 sq km, and encompasses16.35% in the study area. The fourth class comprising partially weathered shale covers an area of 1.15 sq km, which is 6.35%. The fifth class consisting of weathered shale covers 3.14 sq km, which accounts for 17.35%. The sixth class consisting of partially loose debris covers 5.43 sq km, which accounts for 30.00%. The seventh class consisting of loose debris covers 2.29 sq km which accounts for 12.66%.Based on these findings, the following chart (Table 5.4) shows the frequency of landslides in the various classes. The pie chart (Fig. 5.3b) shows the distribution of the various litho-units.

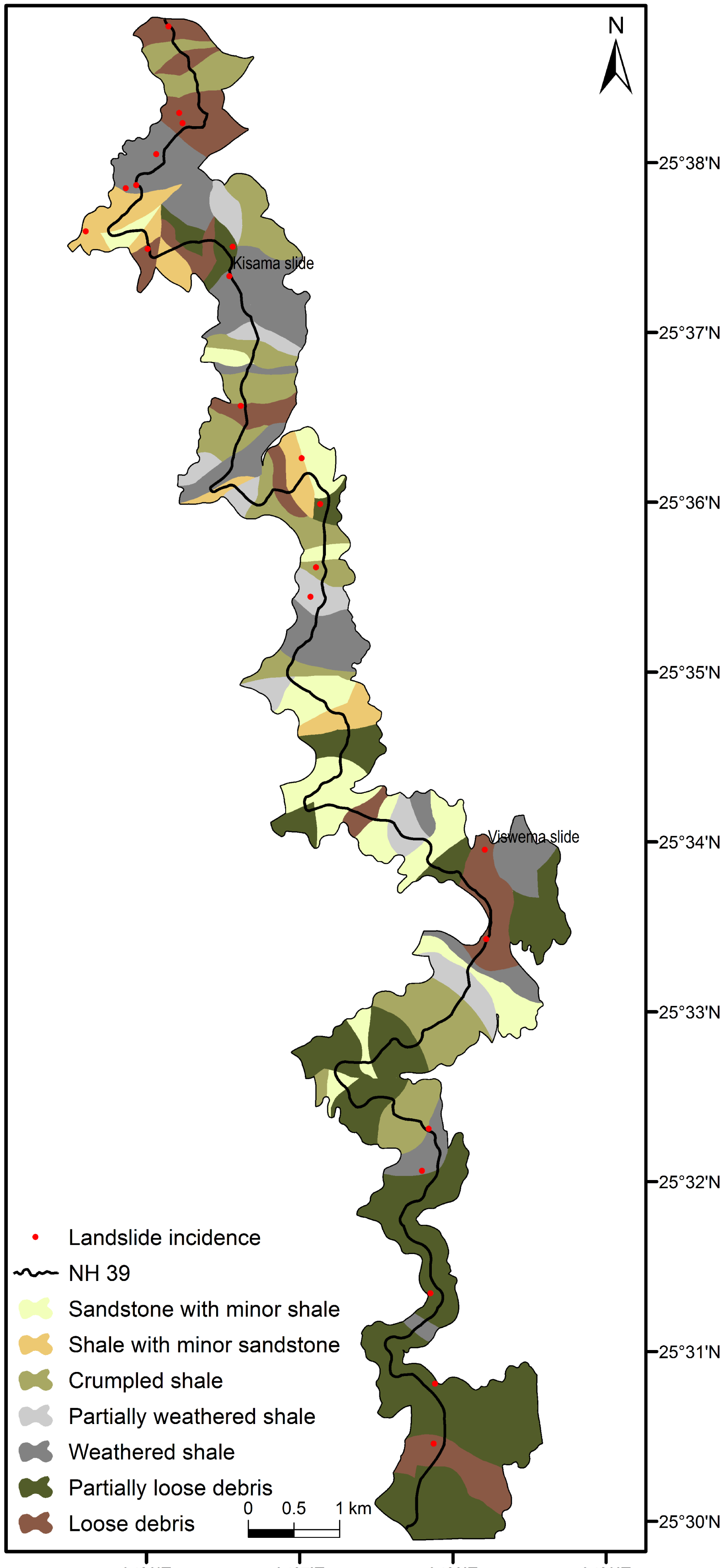


Fig.5.3a. Lithological Map

Table 5.4 Frequency of landslide incidences on Lithology

Category	Area		Landslide		Frequency
	km^2	%	No	%	No/km^2
Sandstone with minor shale	2.13	11.77	-	-	-
Shale with minor sandstone	1.00	5.52	2	9.09	2.00
Crumpled shale	2.96	16.35	1	4.55	0.34
Partially weathered shale	1.15	6.35	1	4.55	0.87
Weathered shale	3.14	17.35	6	27.27	1.91
Partially loose debris	5.43	30.00	4	18.18	0.74
Loose debris	2.29	12.66	8	36.36	3.49

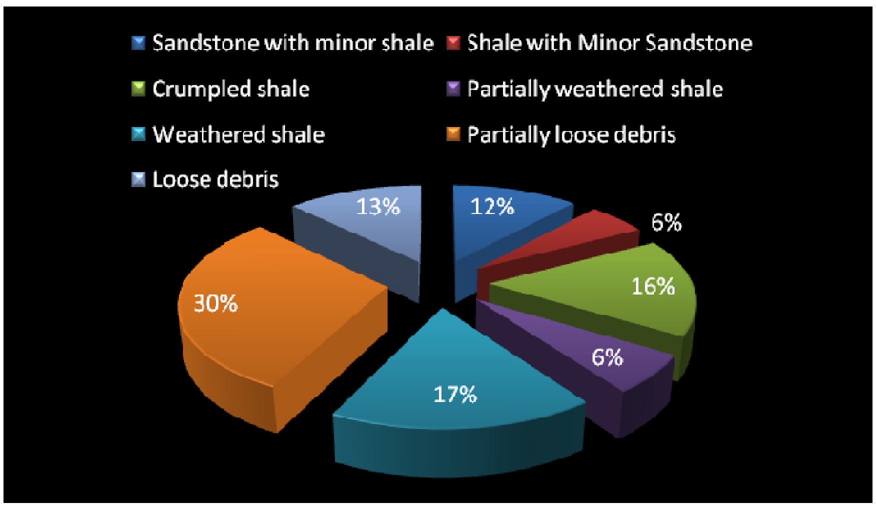


Fig. 5.3b Distribution of litho-units

5.4 Structure

Analyzing the structure of the area, it inferred patterns of bedding planes, several sets of joints, folds, faults, and shear zones. The associations between the direction and inclination of slopes, and character of structural discontinuities have important action on the stability of slopes. Once discontinuity and the line of intersection of two discontinuities tend to parallel the slope, the threat of slope failure heightens. Also with the increasing dip of discontinuity or the plunge of the line of intersection of two discontinuities, the chance of failure also evenly increases. If the inclination of the slope is more than the dip of discontinuity or the plunge of the line of intersection of

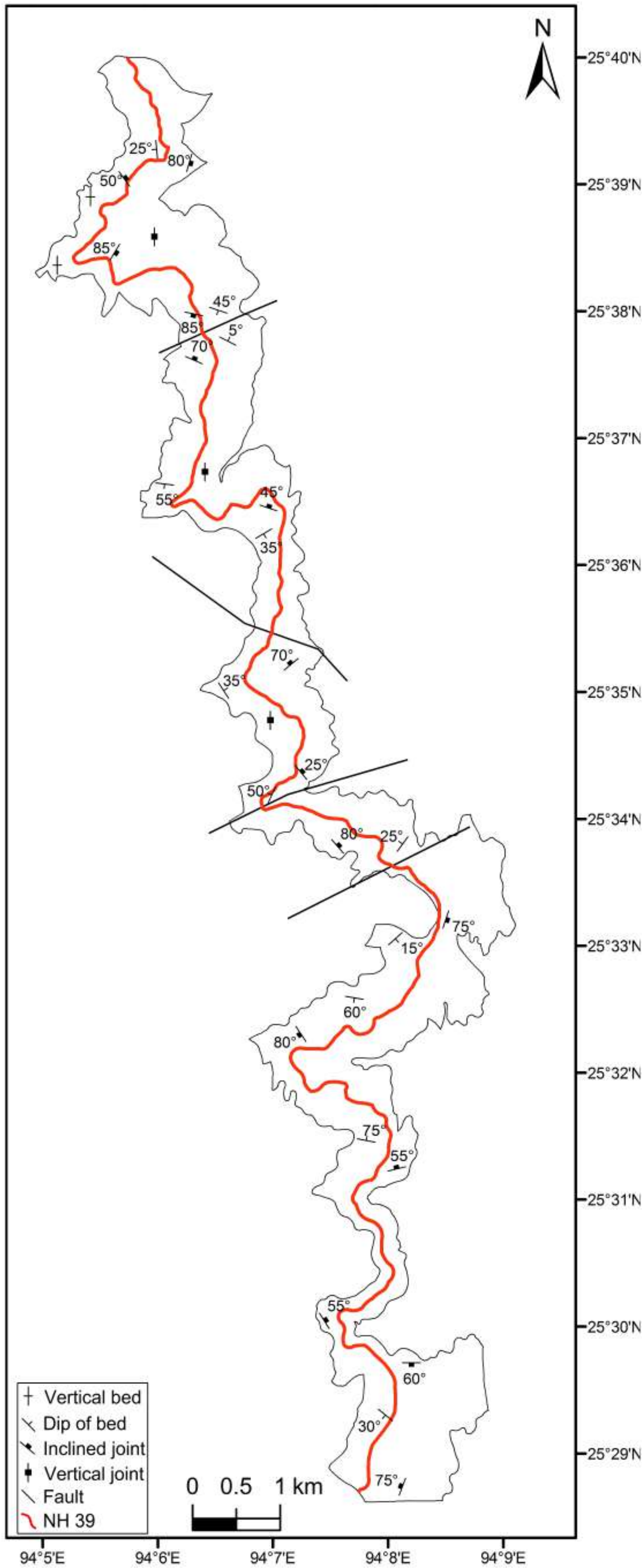


Fig.5.4 Structural Map

two discontinuities, the failure probability remains high. Accordingly, following Romana (1985) LHEF ratings for various stability conditions have been allotted broadly. The discontinuities of concern in this area comprise both bedding and joint planes. The cohesive strength almost gets lost across a discontinuity, that is, one side is entirely removed from the other with only frictional resistance existing between the rock masses. Hence it is certain that most landslides in rock slopes are inhibited essentially by rock structures or discontinuities, which are normally present. The structural map of the area is shown in figure 5.4. Discontinuities of concern in this area include joint planes. The ratings for the various facets of this area are given in table 5.1b. Four faults traversing the study area are mapped using satellite imagery. Three of these trend NE-SW, while one trends NW-SE.

5.5 Groundwater condition

Investigating groundwater from the surface is not practicable nor is its result always correct. However, such methods are less expensive and less time consuming than subsurface investigations. From surface studies four categories of groundwater conditions have been noted (Fig. 5.5a) namely damp,wet, dripping and flowing, for which ratings are assigned (Table 5.1b). Damp and wet groundwater conditions cover 7.55sq km and 4.62sq km respectively, which represent 41.71% and 25.52% respectively. Dripping conditions occur in 5.09 sq km, which represents 28.12%, whereas flowing conditions occur in 0.84sq km, which represents 4.65%.The following chart (Table 5.5) portrays the frequency of landslides on groundwater condition. A pie chart shows the distribution of various categories of groundwater condition (Fig. 5.5b).

Table 5.5 Frequency of landslide incidences on groundwater condition

Category	Area		Landslide		Frequency
	km^2	%	No	%	No/km^2
Damp	7.55	41.71	4	18.18	0.53
Wet	4.62	25.52	3	13.64	0.65
Dripping	5.09	28.12	14	63.64	2.75
Flowing	0.84	4.65	1	4.55	1.19

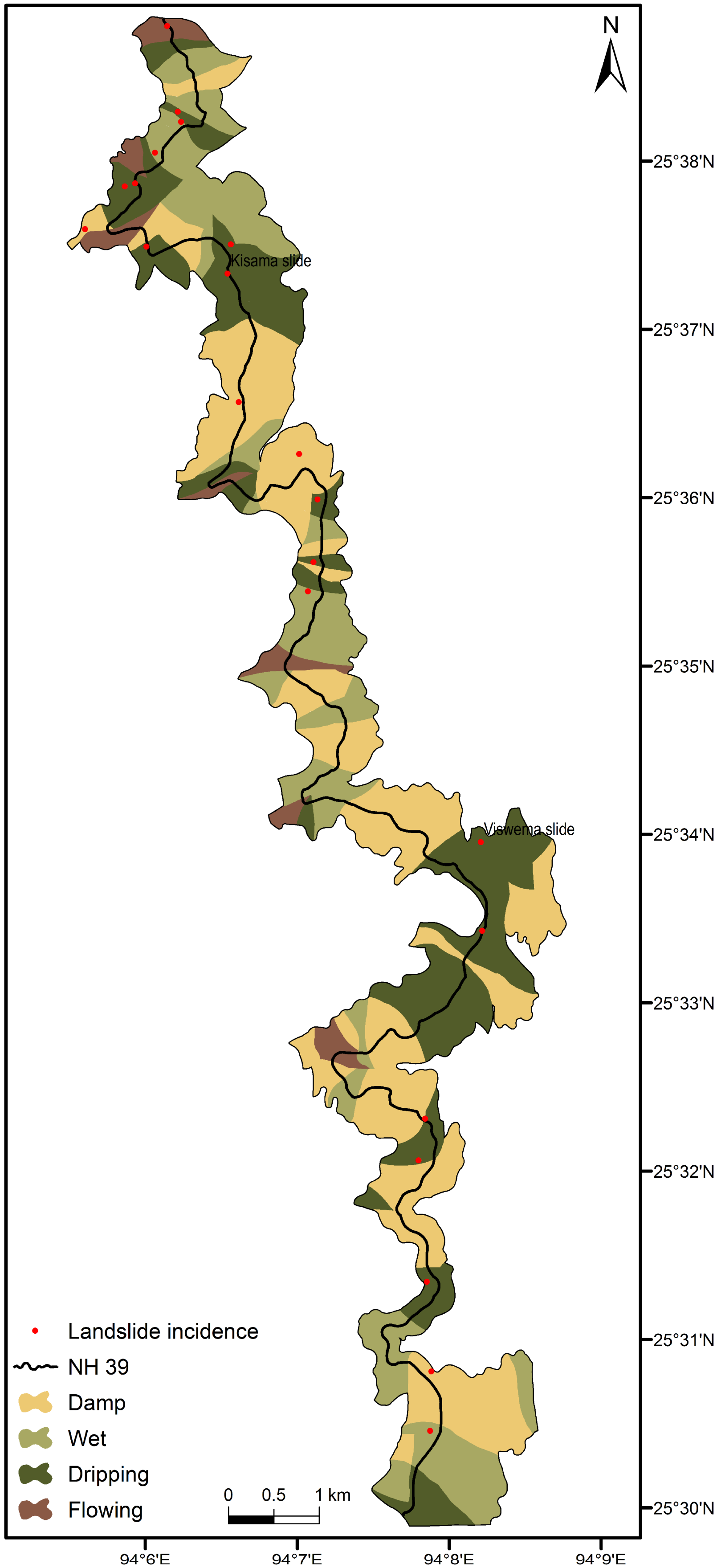


Fig.5.5a. Ground Water Map

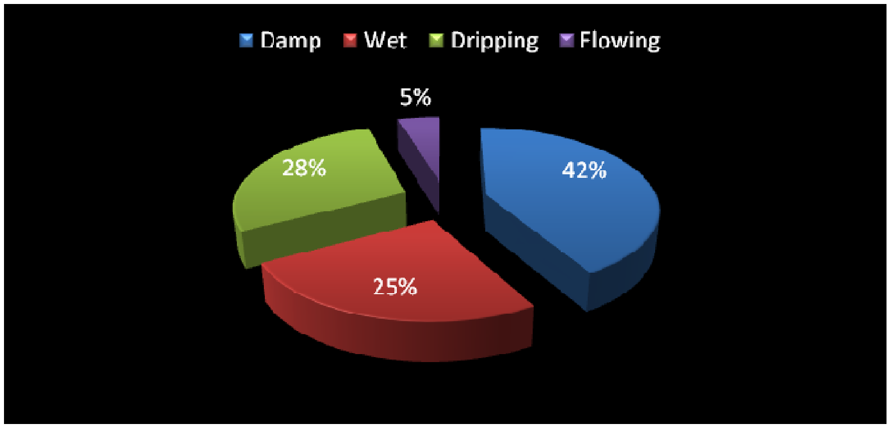


Fig. 5.5b Distribution of groundwater condition

5.6 Land use / land cover

Land use fundamentally refers to man's activities carried out on land. While, land cover includes natural vegetation, water bodies, rock, soil, etc. In the study, landuse / landcover map has been divided under five categories (Fig. 5.6a). The first class comprises populated land which covers an area of 6.15sq km and represents 33.98% of the total area. The second class comprises dense vegetation which occupies 0.25% of the area, covering 1.38sq km. The third class includes moderate vegetation which accounts for 24.59% and covering an area of 4.45sq km. The fourth class consisting of those areas with sparse vegetation occupy 4.46sq km, which is 24.64% of the area. The fifth class comprises terrace cultivation covering 15.41% of the area and covering 2.79sq km. Ratings for land use and land cover categories are given in table 5.1b. The following chart (Table 5.6) portrays the frequency of landslides on land use / land cover. A pie chart (Fig. 5.6b) portrays distribution of land use and land cover categories.

Table 5.6 Frequency of landslide incidences on land use / land cover

Category	**Area**		**Landslide**		**Frequency**
	km^2	**%**	**No**	**%**	**No/km^2**
Populated land	6.15	33.98	5	22.73	0.81
Dense vegetation	0.25	1.38	-	-	-
Moderate vegetation	4.45	24.59	1	4.54	0.22
Sparse vegetation	4.46	24.64	11	50.00	2.47
Terrace cultivation	2.79	15.41	5	22.73	1.79

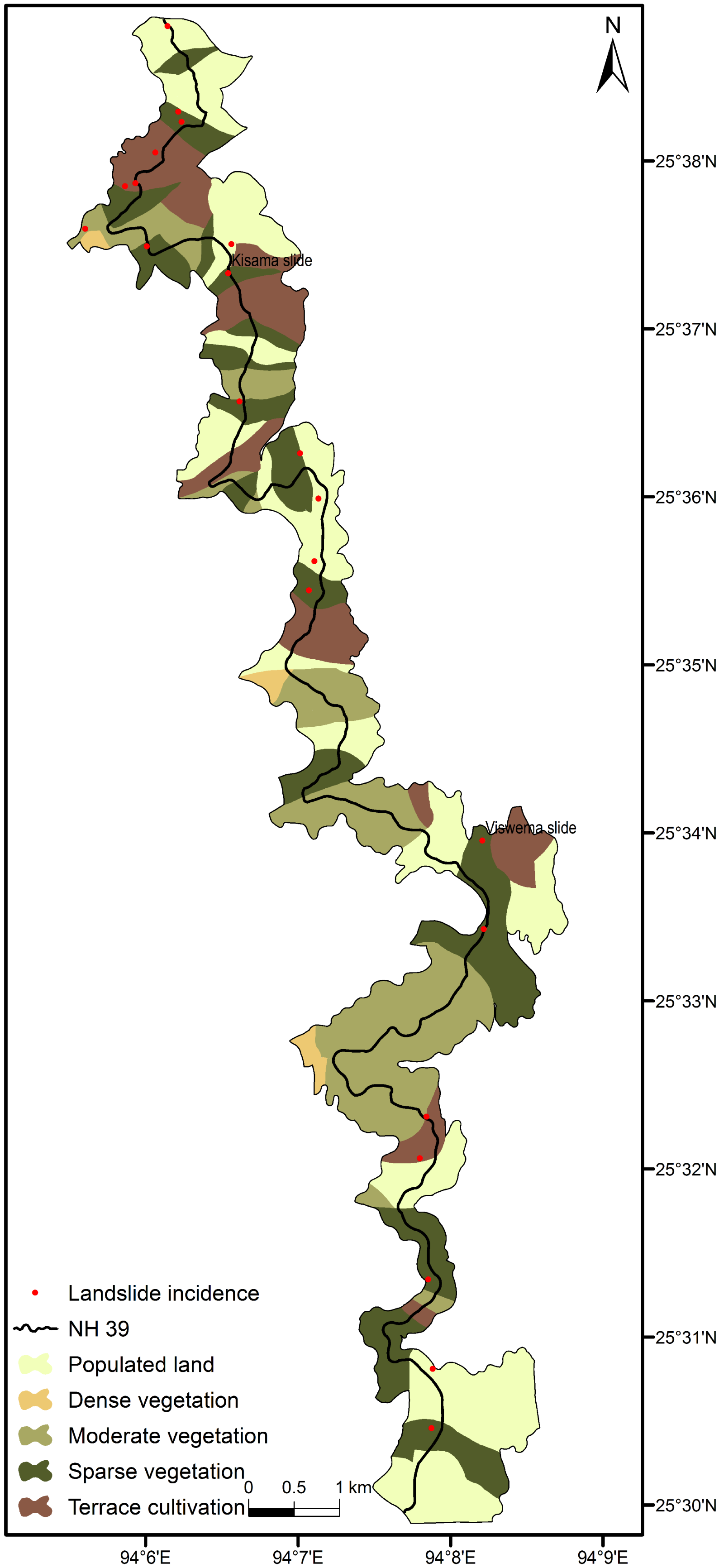


Fig.5.6a. Landuse/Land cover Map

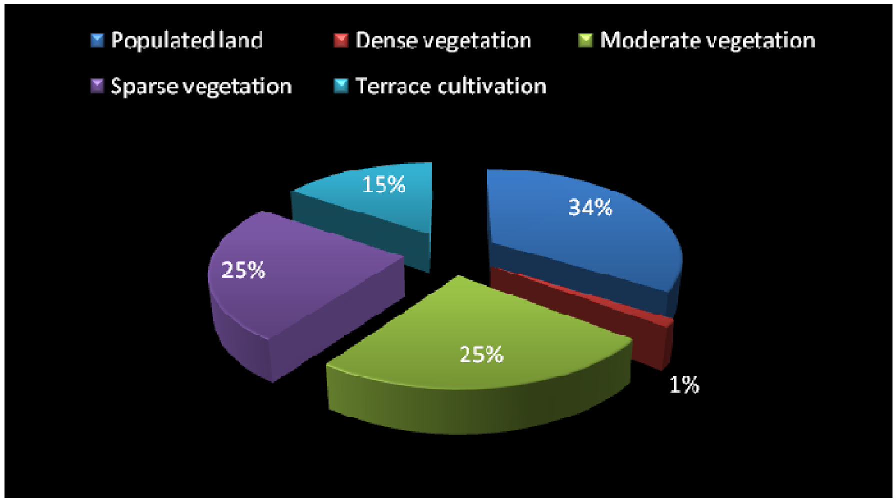


Fig. 5.6b Distribution of various classes of land use / land cover

CHAPTER 6

LANDSLIDE HAZARD ZONATION

6.1 INTRODUCTION

Preface to the study landslides, a wide variety of complex processes was employed that resulted in descending and outward movements under gravity, of diverse materials like mud, slush, rocks, etc. on unstable slopes. Its event is destructive, causing harsh damage to roads, bridges, houses and even loss of lives to those residing in mountainous terrains. The reasons accounted for are many; while some may be due to human actions others due to natural calamities. Landslides are usually prompted by earthquakes, heavy rainfall, road cutting, etc. so; such landslides cannot be completely prevented. But their concentration and severity can be minimized by effective counter measures and preparing for disaster awareness or management. Brabb (1993) accounted that at least 90% of landslides losses can be evaded if the problem is documented before any developmental activities or deforestation initiates. Hence, immense requirement is there for detection of unstable slopes, which can be fulfilled by following a systematic approach for spatial prediction of landslide prone slopes. This calls for a complete evaluation of landslide hazard and preparation of landslide hazard zonation maps.

LHZ mapping is an efficient tool used for detecting those areas that are, or could be, affected by landslides, and calculating the probability of such landslides happening within a specified period of time. It includes identification of zones on a mountainous terrain having varying degrees of proneness to landslides. LHZ maps are methodologically arranged to estimate landslide susceptible zones. Identifying the major sites and executing effective practical approaches for analyzing landslide hazard zonation have been developed.

The preparation of a LHZ map engages the study of the local geology and geomorphic setting, slope conditions including existing and potential instability, and land use datas. Land surfaces are divided into areas, and the relative status of these areas related to degrees of actual or potential hazard from landslides on slopes are traced.Such maps are important as they provide data regarding stability of areas and help in a significant way by minimizing loss to life and property while demarcating zones favourable for development. Scale is an important factor of LHZ mapping. Large scale maps on 1:10,000 or 1:5,000 are engaged for meticulous studies at the local level. In recent years, considerable attention has been done on landslide research in connection with hazard and risk assessment. It has moved ahead in both qualitative and quantitative methods. Qualitative approach needs more understanding on various factors which influence slope stability and using of judgement based on available information, observation and experience. A quantitative or semi-quantitative approach on the other hand needs analytical advancement based on appropriate geological/geotechnical models and/or detailed field observations and/or measurements. In both cases the summative result may be expressed as descriptive categories of hazard or susceptibility such as very high, high, medium, low and very low.

Landslide zonation mapping has been attempted in different parts of the world for about three decades. Blanc and Cleveland (1968) prepared Landslide Hazard Zonation maps of Southern California where the geological formations were classified into different lithologic groups and combined with slope categories, below and above the critical angle. Nilsen and Brabb (1973) did used maps presenting geological formations, slope ranges, and landslide debris to arrange a landslide zonation map of San Francisco Bay region. Varnes (1980) presented a landslide zonation map using slope, soil thickness, land use practice, and drainage as the vital factors. Takie (1982) took into account the type of rock fracturing, weathering characteristics, springs, vegetative cover, valley slopes, etc describing methods to make debris flow hazard maps. Two primary categories of landslide hazard mapping, to be exact direct and indirect mapping was examined elaborately by Hansen (1984). Employing valley density, elevation, slope angle, and formations Kawakami and Saito (1984) prepared a calculated landslide risk map. Wagner et al. (1987) presented preparation of rock and debris slide risk maps for road alignment principle using geological, structural, slope, and geomorphologic factors. ZERMOS the French method for mapping hazard did include factors like lithology, structure, slope morphology, and hydrology where the mapped area is divided into four zones of different levels of hazards with types of movement and direction, activity, and sites of erosion using different symbols.

Brabb et al. (1972) noted slopes of San Mateo County, California relating to percentage of outcrop area of a formation occupied by landslide debris with slope classes. Radbruch and Crowther (1973) studied the California area on the basis of lithology and the number of landslides recorded. In the United States, Radbruch et al. (1976) measured the frequency of slope failure in dissimilar groups of geologic units. An identical grouping of lithology and mass movements was used by Rodriguez et al. (1978) in southern Spain. The essential features used by Varnes (1980) to prepare landslide susceptibility maps were slope, soil thickness, land use practice, and drainage. Koirala and Watkins (1988) explained slope ranking system by adopting preventive measures in the course of excavation. Fugita (1994) submitted the relationship of landslides with the geomorphologic and geological features of SW Japan.

India being a landslide prone country, many experts have attempted mapping of landslide susceptibility taking into consideration the factors and the nature of the terrain. Relying on the frequency of landslides Seshagiri and Badrinarayan (1982) presented hazard zonation of the Nilgiri hills using numerical ratings of slope, land use, soil cover, and drainage. Later Central Road Research Institute (1989) took up zonation mapping considering nature and characteristics of rock and soil materials, the overall stability of slope constituting formations, slope angle, condition of slope surface, hydrological features, and toe erosion which were measured quantitatively. Thus overall ratings of slope stability were divided into three categories as very good, good, and fair. Regarding slope, lithology, structure, and earthquake epicentres Choubey and Litoria (1990) presented a LHZ map of the Garhwal Himalaya. Gupta and Joshi (1990) studied the Himalayas by means of a GIS approach giving index values to aspects like land use, lithology, major tectonic features, and azimuth of landslides. Mehrotra et al. (1992) assembled a landslide susceptibility index considering factors such as lithology, slope angle, distance from major thrusts and faults, land use pattern, and drainage density related to frequency of existing landslides. Anbalagan (1992) carried out mapping on factors such as slope, lithology, structure, relative relief, land use and land cover, and groundwater conditions of Kathgodam- Nainital area in the Kumaon Himalaya where the LHEF rating scheme was planned. It represents demarcation of facets, preparation of thematic maps, estimation of LHEF ratings, calculation of TEHD values and construction of a LHZ map of the area even with lack of data on topography, climate, geology, hydrogeology, seismicity and anthropogenic activity and their components or variables. However, Thigale et al. (1998) clarifies that a lot of complications prevail in preparing LHZ maps.

Instability of land area in Kohima town was studied by Walling (2005) where he presented a LHZ map using RS and GIS. Aier (2005) compiled a number of mitigation measures in the course of preparing a LHZ map along the NH 29 between Chumukedima and Kohima. Hiese (2005) projected a risk map of Kohima town and its surrounding. A grid-based method for organizing the terrain into five categories was suggested by Deva and Srivastava (2006). It utilized three factors including lithology, ruggedness number, and land use / land cover. An effort on risk zonation of the area in Garhwal Himalaya was performed by Pachauri et al. (2006) and conclusively added that rock fall velocity modeling can be used in landslide risk zonation. Related to the study in Chamoli area of Uttarakhand on LHZ mapping, Pachauri (2007), relates that facet-based LHZ is a very efficient tool for landslide mapping, and is cost effective in high relief areas of the Himalayan region.

Landslide susceptibility mapping is a way to logical and uniform identification and risk assessment of areas vulnerable to landslides; however, such work has not been earnestly attempted till date. Some of the earliest works in GIS environment was done by Carrara et al. (1991), Kingsbury et al.(1992), van Westen (1994), Nagarajanet al.(1998), Gupta et al.(1999) and Dhakal et al.(2000). With time this gap is being filled today with the present diffusion of hardware and software tools allowing earth science data to be efficiently and cost-effectively processed. At the present, various commercial systems are offered in the market; they vary in terms of hardware requirements, potential of spatial functions, efficiency of the database, and internal data structure like vector or raster models. RS and GIS technologies have gained prominence and contributed noteworthy product for spatial data analyses. They have confirmed to be very helpful and important tools for landslide studies. (Carrara, 1983; Carrara et al., 1991; Soeters et al., 1991) have rightly said that researchers have exploited RS and GIS technologies to develop and investigate data that are significant in evaluation of natural hazards. In recent times using of RS data and techniques for land surface change detection has achieved a lot of attention. For identifying landslides

Cheng et al. (2003) used RS techniques utilizing multi-temporal satellite imagery. To evaluate landslide hazard Ohlmacher and Davis (2003) opted multiple logistic regression and GIS technology. Utilizing vector and raster data it gives a great impact on the functionality of each system performing different classes of operations (Burrough, 1986; Aronoff, 1989; Laurini and Thompson, 1992). Its growth has led to rapid development of landslide hazard assessment methods (Aleotti and Chowdhury, 1999). In the present scenario, RS and GIS, with the help of computer software have achieved greater heights. GIS is a unique tool to store large amounts of data, including features of upgrading and analyses. Hence, landslide hazard is studied basing on statistical analyses, a physical approach or deterministic approach.

Statistical approach

Statistical approach connects all aspect on the foundation of investigational relations with past and present landslide events. Variation of factors that led to landslides in the past are resolved statistically where quantitative predictions for areas presently free of landslides but on conditions where similarities exist. In bivariate numerical studies, individual factor map is incorporated with the landslide map where weighing values based on landslide densities are calculated for every class. Similar such method is engaged in the Information Value Method (Yin and Yan, 1988; Sridevi and Sarkar, 1993). Another method is the multivariate statistical approach where each factor maps are modeled either on a grid basis or in morphometric part. Then on each sampling sections, the presence or absence of landslides is determined. The output can then be analysed using discriminant analysis, or multiple regression analysis (Carrara, 1983). A multivariate statistical model for assessing landslide hazards was then viewed by Chung et al. (1995). Other numerical technique regarding use of information models and fuzzy set theory were studied in this perspective (Yin and Yan, 1988; Juang et al., 1992; Jade and Sarkar, 1993). Later on Raj et al. (2011) estimated LHZ by means of the relative effect (RE) scheme in the south-eastern Nilgiris. This technique determined the RE of each unit using surface geology; slope morphometry, climatic conditions, and land use and land cover whereby calculating the ratio of the unit portion in coverage and landslide.

Heuristic approach

According to this method, landslide manipulating factors such as lithology, structure, slope morphometry, land use and land cover, drainage density, etc. are scored according to their assumed or expected importance in causing mass movements. This study employs prior knowledge accessible to experts on various causes of landslides in the area of investigation and knowledge is dependent on the experience of the expert. Abella and van Westen (2008) analyzed the heuristic model by examining the diverse landforms and the causative factors for landslides. The technique involves weights allocated by expert judgment and also components which includes slope angle, internal relief, slope shape, geological formation, active faults, distance to drainage, and distance to springs, geomorphological subunits, and existing landslide zones. Gahgah et al. (2009) examined GIS based LHZ using the heuristic method deliberating on factors related to landslide occurrence with factors such as lineaments, soil map, lithology, roads, drainage pattern, and rainfall together with slope angle and elevation from DEM. All these inputs were considered important for landslide hazard assessment and were then integrated into GIS for data processing.

Deterministic approach

The benefit of this method is its validity using geotechnical analyses to integrate landslide geometry, geotechnical properties of sliding material, and groundwater parameters and allowing the calculation of quantitative values of stability in terms of factor of safety (Jelínek and Wagner, 2007). It is summarized that the technique can be applied in huge scale for an individual landslide. It is particularly worked on problematic sites where the geomorphological and geological conditions are practically homogeneous. Nevertheless, complete knowledge of the area has to be inculcated keeping in mind that the key role to the successful analysis of any related study is the input data and parameterization of the primary geotechnical model. This method is helpful in reasonably recognizing unstable areas within the studied area and also to forecast potential slope instability if the mechanism of landslide is correctly defined.

Mapping of the targeted area is deliberated following Anbalagan (1992) and the approbation of the Department of Science and Technology (1994) and Bureau of Indian Standards (1998). The present study of LHZ mapping takes into consideration of the slope morphometry, relative relief, lithology, relationship of structural discontinuities with slope, groundwater condition, and land use and land cover. Thematic maps are created for slope, relative relief, lithology, structure, groundwater condition, and land use and land cover. For the contributory factor LHEF is allocated. The rating scheme of Anbalagan is a numerical system managed by the major causative factors of slope instability that aids in determining landslide vulnerability of a slope. The thematic maps created are then superimposed on the thematic layers in a GIS platform thus providing the required data for the LHZ map. And on the basis of the distribution of the TEHD values a LHZ map is generated. Thus landslide hazard map plays an important role to avoid unstable areas and also in minimizing loss of life and property. It also helps us to adopt appropriate mitigation or remedial measures. All in all, it gears us up for development and for safety.

6.2 LANDSLIDE HAZARD ZONATION MAPPING

The LHZ map demarcates the area of study into four different classes comprising low, moderate, high and very high hazard zones (Fig. 6.1a). Low hazard zones occupy an area of 0.5sq km. This represents 2.76% of the total area of study. Moderate hazard areas cover 2.54sq km, which is 14.03%. High hazard areas occupy 51% covering 9.23sq km, while very high hazard areas occupy 5.83sq km, which is 32.21% of the total area. Ratings for the various hazard zones are generated (Table 5.1). Table 6.1 shows the frequency of landslides on the various hazard classes. The pie charts depict the distribution of hazard zones and the frequency of landslide incidences on hazard zones (Figs. 6.1b).

Table 6.1 Frequency of landslide incidences on hazard zones

Category	**Area**		**Landslides**		**Frequency**
	km^2	**%**	**No**	**%**	**No/km^2**
Low hazard	0.50	2.76	-	-	-
Moderate hazard	2.54	14.03	-	-	-
High hazard	9.23	51.00	7	31.82	0.76
Very high hazard	5.83	32.21	15	68.18	2.57

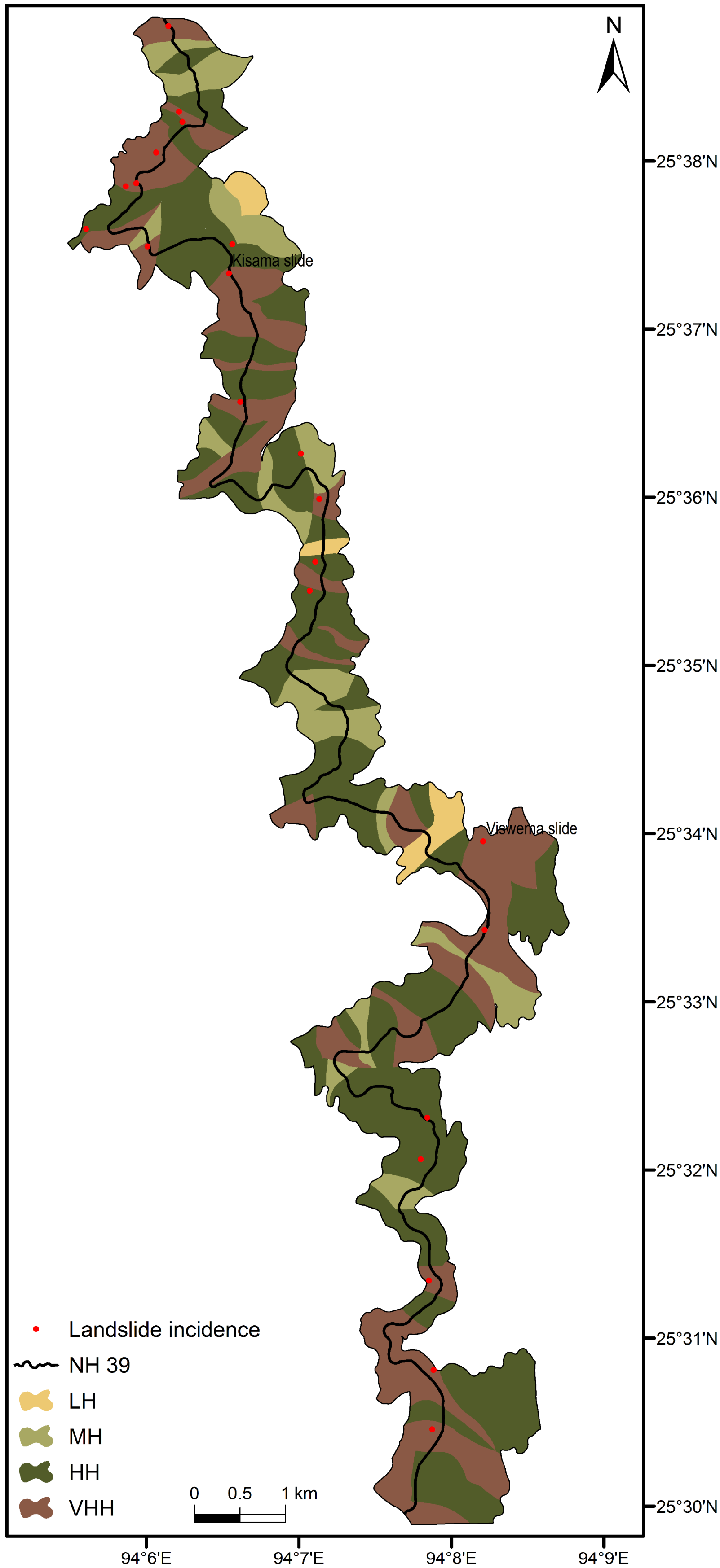


Fig.6.1a Landslide hazard zonation map

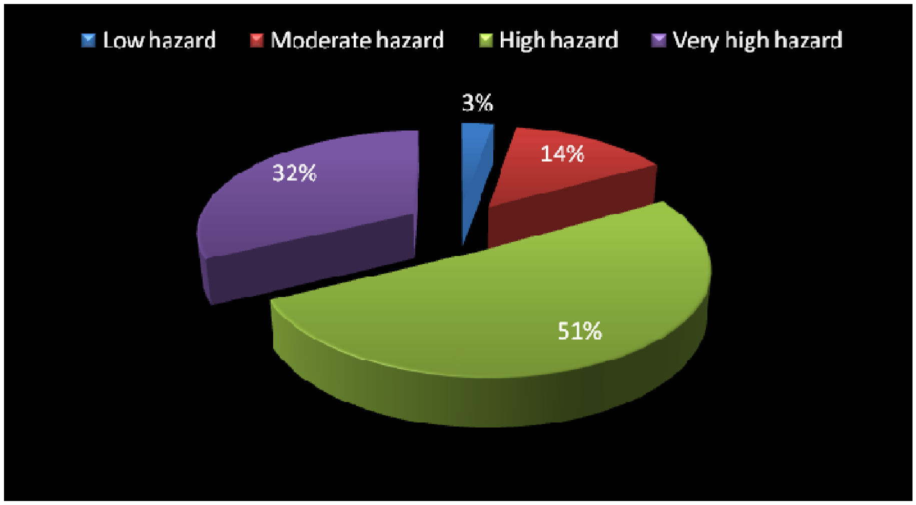


Fig. 6.1b Distribution of hazard zones

Plate 2.1 Spheroidal weathering

Plate 7.1.a Creeping indicated in man made structure

CHAPTER 7

RISK ANALYSES

Like landslides found in different sections of the world the slides in this area too have been caused due to diverse factors. Some of the landslides in this area have cropped up at the sites of ancient landslides which have been reactivated. Investigations have revealed that along this section of the highway, a number of landslides occurred in the past. Nilsen et al (1976) is of the opinion that areas of abundant recent landslides often coincide with areas of ancient landslide deposits.

Instability in the form of slumps, rockslides, rock falls, gully erosion, creep, and subsidence has been distinguished along this highway. These landslides of varying magnitudes commonly occur during monsoon, thereby causing blockage of very strategic road that connects the states of Nagaland and Manipur (Anand, 1988). It is eminent that in this area some landslides are road-induced. Debris slides, debris falls, and rock falls are some type of landslides that occur in this part. Besides, natural environmental features such as rainfall, topography, structures, nature of slopes, drainage conditions, and properties of the material forming the slopes, excavation of rocks and slope modification for agriculture are also some contributory factors causing portions of the area to slide down. In most cases no single factor can be blamed to the cause of any landslide. Studies have been carried out to determine the causes of landslides along this highway.

For purposes of detailed studies two landslides along the highway between Kohima and Mao that are active or are potential threats are taken into consideration. Each section is thoroughly analyzed and appropriate measures provided based on the causes or the probable modes of failure.

7.1 LOCATION 1-KISAMA SLIDE

Introduction

The area where the debris slide took place lies between 25°37’15.78” & 25°37’21.74” N latitudes and 94°6’47.60” & 94°7’4.89”E longitudes, covering an area of

41475.29sq m. This slide has also affected about 150 m stretch of the NH 39 (Fig. 7.1).This is a multi-rotational slide that was subject to prolonged creep. Local creep still continues as is indicated by the condition and movement of man-made structures and trees (Plate 7.1.a). Continuous creep has been taking place since the landslide first gave way during the 1950’s, and often after that. Recently it occurred again in 2013 in the early part of July and affected a length of about 600m in length and breadth of 120m (Plate 7.1.b)

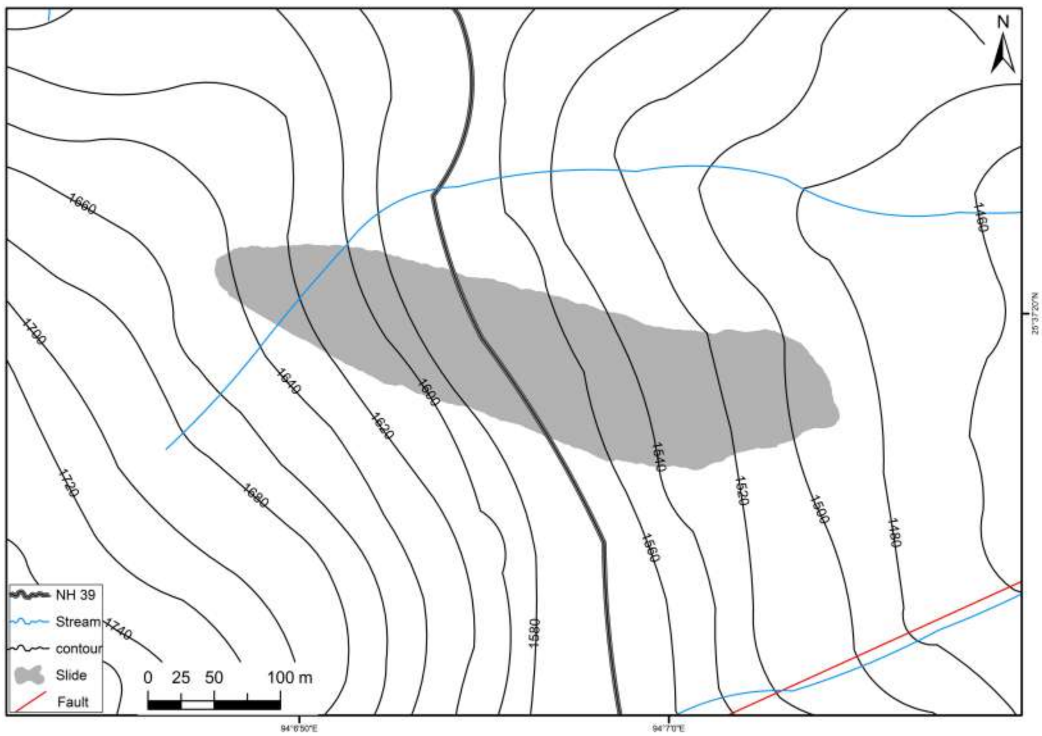


Fig. 7.1 Location map

7.1.1 Geology and structure

The area under investigation is a reactivated old slide and the Barail rocks have been severely affected by tectonism as seen by the highly jointed, fractured and sheared nature of the rocks (Plate 7.1.1a). A lineament trending NE-SW, traverses this area. Rock dips are variable due to local structural disturbances. Slickenside provides evidence (Plate 7.1.1.b) of the direction of movement. The general trend of the slope varies from 50°-60° in a NE direction. The rocks exhibit two prominent sets of joints. The first set of joints dipping at an angle of 35°, trends NW-SE. The second set dips

Plate 7.1.b Kisama Slide area

Plate 7.1.1.a Highly jointed and fractured sandstone

Plate 7.1.1.b Slicken sides

Plate 7.1.2.a Drains choked by debris

40° and trends NNE-SSW. The shale present is highly susceptible to weathering and disintegrates on exposure to air.

7.1.2 Causes and effects

This is a palaeoslide zone that was reactivated due to prolonged and heavy rainfall. Evidence for the palaeoslide is the presence of huge accumulations of rock and soil debris. The crown of the slide lies above the highway. Excavations for widening of the highway without considering stability left the slopes as high as 22m at angles of about 70º without any support. Slide material had caused water to concentrate in the road where the drains are choked by debris due to unscientific road construction and lack of breast walls to hold back the debris of the upper slopes (Plate 7.1.2.a). On the highly jointed rocks and loose soils, water seepage is high, mainly in the upper slopes (Plate 7.1.2.b). It also led to water retention and subsurface saturation from the terrace cultivation on the lower portion of the slide zone, leading to build-up of extreme pore-water pressure ultimately giving way to a major slide. Triggering the slide is the weight and vibrations from vehicular movement on the semi-consolidated mass. All these factors have combined to aggravate the situation in this zone. And as the dry season approaches the water table goes down considerably where the road surface sinks which is indicated in many places along this part of the highway.

The slide was so massive that the normal flow of traffic to and from Kohima and Manipur was disrupted for few days. Due to this landslide the main road was totally damaged up to a length of 120m. Hundreds of trucks with essential commodities were stranded on the road for many days hampering the lives of the local people and the people of Manipur state. A high tension cable tower near the head of the slide had tilted to about 20º and is literally sinking (Plate 7.1.2.c). It is still unattended to, and poses great threat to the local people. A house in the vicinity has been badly damaged. The magnitude of damage caused by this slide is very high.

7.1.3 SMR and Kinematic analyses

a) Slope Mass Rating

For demarcation of weak areas the SMR technique is mainly used for estimation of slope stability. Forty rock samples are collected from the slide zone to determine the

Plate7.1.2.b Water seepage from upper slope

Plate 7.1.2.c Tilted High Tension Power Line

strengths of rocks using a PLIT (Table 7.1). An RMR rating of 39 is obtained from the slide location which indicates more or less weak rocks. SMR values falling in Class IV indicate unstable slope conditions. This area suffers from potential planar and/or wedge type of failure. This requires extensive corrective measures. The slide zone itself is very weak.

Table 7.1 Slope mass rating

	Value or Condition	**Rating**
1. Point Load Test	2.6 MPa	12
2. RQD	17%	3
3. Spacing of joints	25 mm	5
4. Condition of joints	Slightly rough; separation <1 mm; soft joint wall rock	12
5. Groundwater condition	Moist	7
RMR	*(1+2+3+4+5)*	***39***
6. $F_1 = (1 - \text{Sin}I\alpha_j - \alpha_s I)^2$	20°	0.40
7. $F_2 = \text{Tan}^2\beta_j$ or $F_2 = 1$ for toppling	35°	0.70
8. $F_3 = I\beta_j - \beta_s I$ for plane failure $= I\beta_j + \beta_s I$ for toppling where β_s= dip/angle of slope	-15°	-60
9. F_4 = Adjustment factor	Pre-splitting	10
SMR *= RMR+(F₁xF₂xF₃)+F₄*	*39+{0.40x0.70x(-60)}+10*	***32.2***
10. Class	IV	
11. Description	Unstable	

b) Kinematic analysis

To determine the mode of failure in jointed rock masses, kinematic analyses are performed. About 200 joint attitudes are taken from the field and plotted in pole (Fig. 7.1a) and contour diagrams (Fig. 7.1b). From the contour diagrams, two dominant joint sets are identified (J_1: 35°→40°, J_2: 40°→100°), which are plotted against slope (50°→60°) in a stereographic projection (Fig. 7.1c).

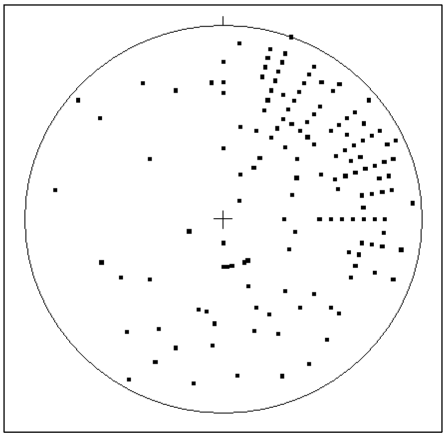


Fig. 7.1a Pole diagram

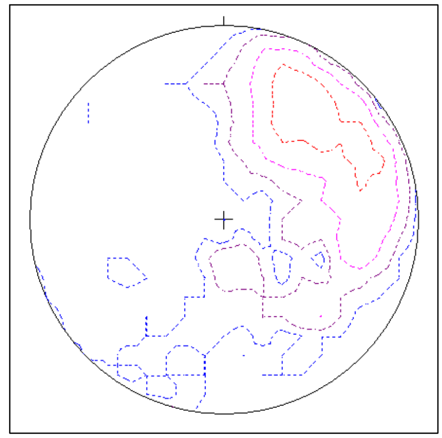


Fig. 7.1b Contour diagram

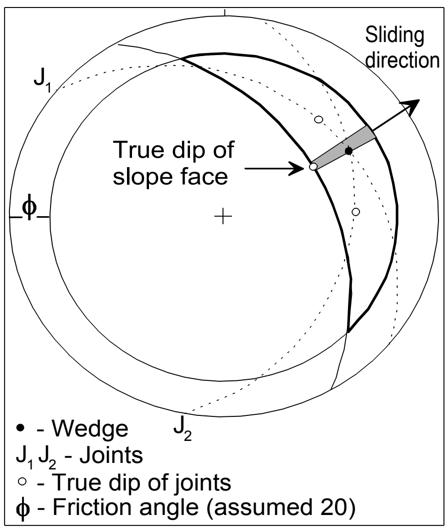


Fig. 7.1c Stereogram

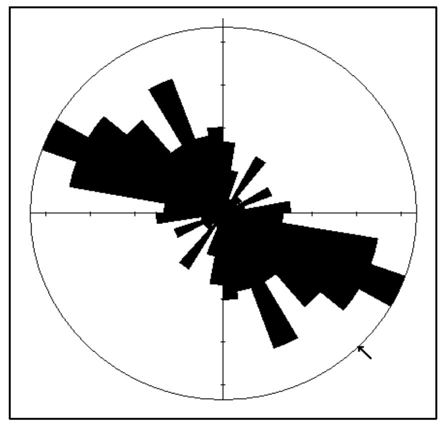


Fig. 7.1d Rosette

The true dips of the joint planes $J_1$and J_2 lie outside the shaded region. Here double plane wedge type of failure is inferred (Yoon et al., 2002). Examination of the intersections of these joints indicates that wedges form small blocks in the rocks. J_1 plotted against slope shows planar failure. It is therefore concluded that both planar and wedge failure have occurred and are likely to occur in the future.

Incorporating the joint data a rosette is constructed to understand the orientation of the lineaments with respect to the regional trend (Fig.7.1d). The rosette shows that majority of the joints and fractures of the slide area have roughly NW-SE orientation. This indicates possible tensile fractures affecting the rocks. Antithetic shearing stresses have also played a role in rock deformation. The tensile stresses have caused extensive deformation of the rocks leading to large scale fracturing and jointing.

Results from RMR points out that the rocks in the slide zone are very weak. SMR assessment indicates that the slope is unstable and that planar and wedge failure are responsible for the slides. Hence, the area is likely to be affected by further debris slides in the near future, particularly during heavy and prolonged rainfall.

7.1.4 Geotechnical analysis of soil and Direct Shear Test

Geotechnical studies of the soils from the landslide area such as consistency limit and shear strength parameter were carried out.

a) *Geotechnical analysis of soil*

Soil samples were collected from the landslide affected area (K_1, K_2, K_3).One sample each was collected from the adjoining stable area (K_4). A series of laboratory tests were carried out to ascertain the geotechnical properties of these soils.

Table 7.1a Data and observation sheet for liquid limit

Sample No. K1

Container No	**1**	**2**	**3**	**4**
Weight of container (g)	5.76	6.09	12.51	6.13
No.of blows	28	17	34	23
Weight of container + wet soil (g)	26.02	30.02	40.19	25.93
Weight of container + dry soil (g)	19.35	21.95	31.31	19.40
Water content (%)	49.08	50.88	47.23	49.20
Liquid limit (W_L) = 49% *Flow index (I_f) = 17.5%*				

Sample No.K2

Container No	**5**	**6**	**7**	**8**
Weight of container (g)	6.13	8.55	10.35	9.22
No.of blows	27	32	17	33
Weight of container + wet soil (g)	28.74	28.59	36.48	35.42
Weight of container + dry soil (g)	22.82	23.37	29.36	28.55
Water content (%)	35.47	35.22	37.45	35.02
Liquid limit (W_L) = 36 % *Flow index (I_f) = 9.5%*				

Sample No. K3

Container No	**9**	**10**	**11**	**12**
Weight of container (g)	9.46	9.85	8.71	8.86
No of blows	15	19	34	22
Weight of container + wet soil (g)	31.28	36.97	29.66	30.78
Weight of container + dry soil (g)	25.11	29.48	24.02	24.73

Water content (%)	39.42	38.15	36.84	38.12
Liquid limit from graph (W_L) = 37.5 % *Flow index from graph (I_f) = 12.5 %*				

Sample No. K4

Container No	13	14	15	16
Weight of container (g)	5.76	9.16	10.05	6.46
No of blows	24	17	21	16
Weight of container + wet soil (g)	28.80	33.27	32.30	26.01
Weight of container + dry soil (g)	21.11	24.99	24.66	19.26
Water content (%)	50.09	52.30	52.29	52.73
Liquid limit (W_L) = 50 % *Flow index (I_f) = 22.5 %*				

Table7.1b Data and observation sheet for plastic limit

Sample No.K1

Container No	1	2	3
Weight of container (g)	6.29	9.13	9.10
Weight of container + wet soil (g)	7.30	10.75	10.19
Weight of container + dry soil (g)	7.07	10.37	9.93
Water content (%)	29.49	30.64	31.32
Average water content (W_P) =30.48 %			

Sample No. K2

Container No	4	5	6
Weight of container (g)	9.81	9.13	9.32
Weight of container + wet soil (g)	11.17	10.12	10.36
Weight of container + dry soil (g)	11.02	10.00	10.24
Water content (%)	12.50	13.79	12.90
Average water content (W_P) =13.06 %			

Sample No. K3

Container No	7	8	9
Weight of container (g)	6.39	6.35	6.14
Weight of container + wet soil (g)	8.04	7.06	6.77
Weight of container + dry soil (g)	7.76	6.92	6.65
Water content (%)	20.44	24.56	23.53
Average water content (W_P) =22.84 %			

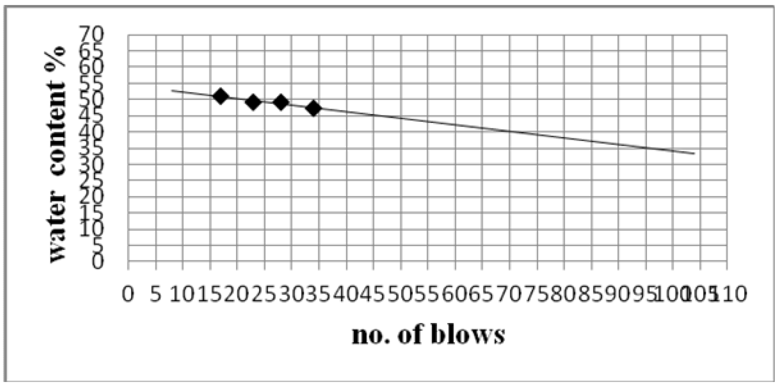
Sample No. K4

Container No	10	11	12
Weight of container (g)	9.65	14.35	9.10
Weight of container + wet soil (g)	10.75	15.31	10.00

Weight of container + dry soil (g)	10.54	15.11	9.85
Water content (%)	23.59	20.00	20.00
Average water content (W_P) =21.19 %			

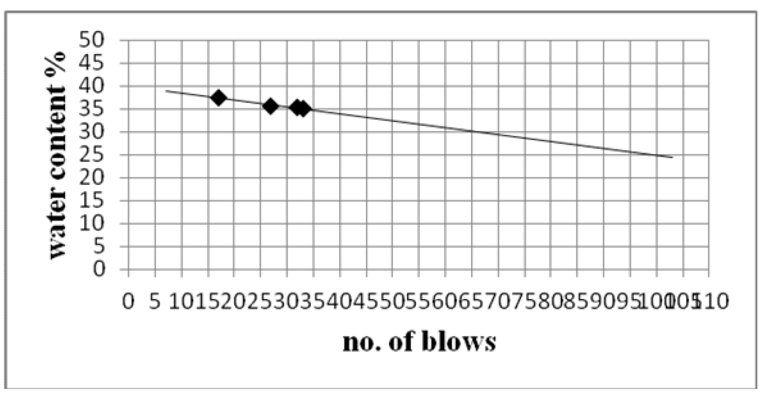
Fig. 7.1e Liquid limit graph

Sample No. K1



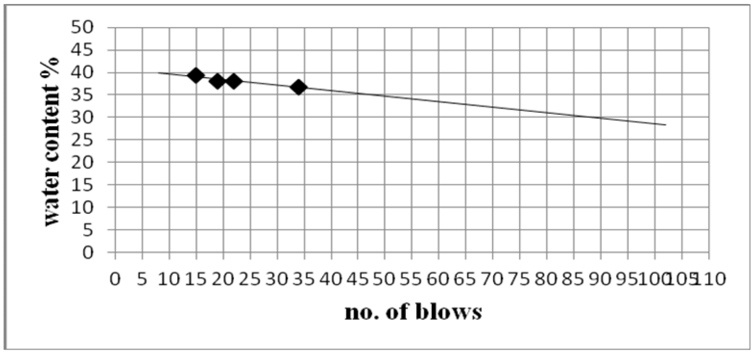
No. of blows	28	17	34	23
Water content	49.08	50.88	47.23	49.2

Sample No. K2



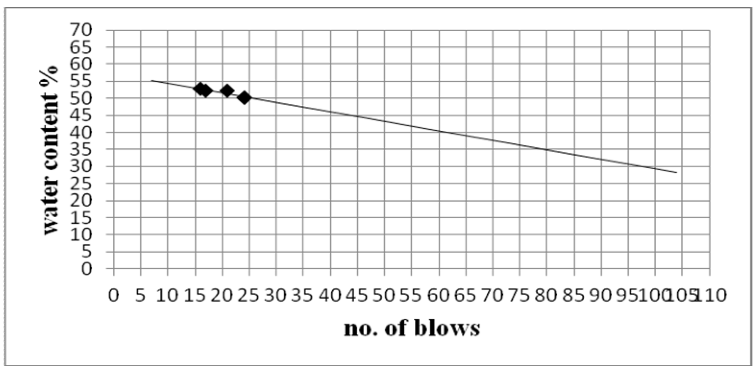
No. of blows	27	32	17	33
Water content	35.47	35.22	37.45	35.02

Sample No. K3



No. of blows	15	19	34	22
Water content	39.42	38.15	36.84	38.12

Sample No. K4



No. of blows	24	17	21	16
Water content	50.09	52.30	52.29	52.73

Table 7.1c Data and observation sheet for shrinkage factor

Sample No	**K1**	**K2**	**K3**	**K4**
Container no	**1**	**2**	**3**	**4**
(a) Water content of wet soil				
1. Weight of shrinkage dish (g)	6.18	5.92	31.19	6.51
2. Weight of shrinkage dish + wet soil pat (g)	39.22	41.40	69.03	39.34
3. Weight of shrinkage dish + dry soil pat (g)	27.01	30.84	56.71	26.98
4. Weight of dry soil pat (W_0) (g)	20.83	24.92	25.52	20.47
5. Weight of wet soil pat (W) (g)	39.22	41.40	69.03	39.34
6. Moisture content (M) (%)	58.62	42.37	48.27	60.38
(b) Volume of wet soil pat				
7. Volume of mercury or volume of wet soil pat in ml (V)	317.06	309.67	341.60	315.08
(c) Volume of dry soil pat				
8. Volume of mercury displaced by dry soil pat in ml (V_0)	213.27	222.00	242.01	215.45
9. Shrinkage Limit (S_L) (%)	21.95	16.53	19.59	24.58

10. Shrinkage Ratio (S_R)(%)	1.672	1.85	1.70	1.57
11. Volumetric Shrinkage (V_S) (%)	59.40	47.80	48.75	56.20

Table 7.1d Consistency limit Determination of soil samples from Kisama slide

Sample no	Natural water content	Plastic Limit (W_P) %	Liquid Limit (W_L) %	Plasticity Index (I_P) %	* Liquidity Index (I_L) %	* Consistency Index (I_C) %	Flow Index (I_f) %	Toughness Index (I_T) %	Shrinkage Limit (S_L) %	Shrinkage Ratio (SR) %	Volumetric Shrinkage (V_S) %
K1	29.78	30.48	49.00	18.52	-0.04	1.04	17.50	1.06	21.90	1.67	59.40
K2	18.81	13.06	36.00	22.94	0.73	0.27	9.50	2.41	16.53	1.85	47.80
K3	20.98	22.84	37.50	14.66	0.47	0.53	12.50	1.17	19.59	1.70	48.75
K4	17.99	21.19	50.00	28.81	0.30	0.70	22.50	1.28	24.58	1.57	56.20

- *Values calculated with highest natural water content*

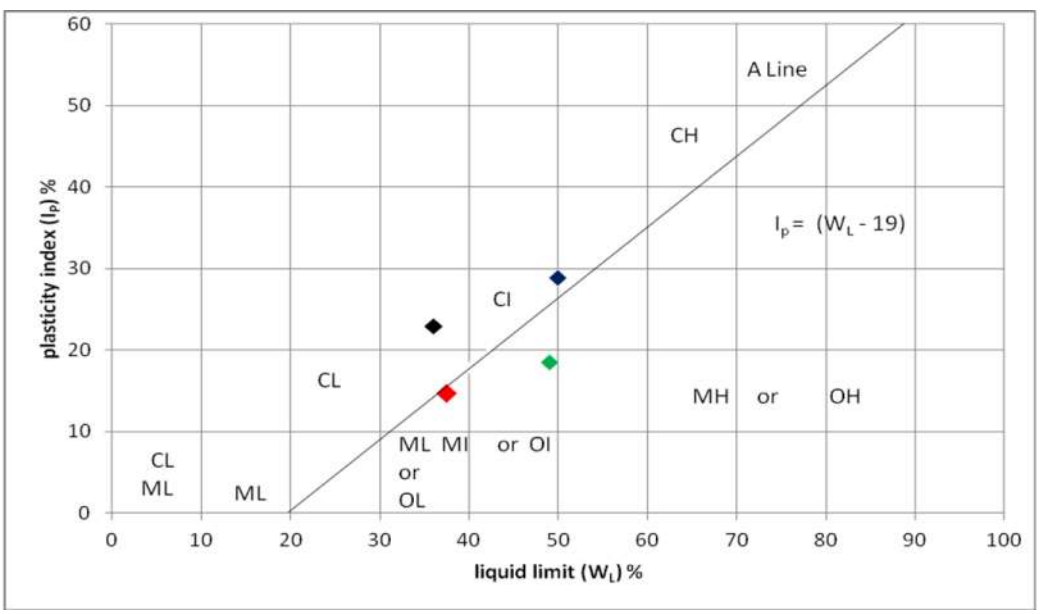


Fig. 7.1f Plasticity chart for soils of Kisama slide (IS: 1498-1970)

Liquid limit (W_L)	49.00	36.00	37.50	50.00
Plasticity index (I_p)	18.52	22.94	14.66	28.81

Plastic limit and liquid limit are important factors that help to understand the plasticity and consistency of a soil. High plastic soils have higher shearing strength whereas lean soils possess low shearing strength. In order to understand the firmness of the soils, consistency limits of the soils of the slide area are evaluated (table 7.1.d)

Plasticity chart prepared for the soils indicate that soil samples falls under CI and MI group indicating that these soils are inorganic clay with silt having intermediate plasticity or compressibility. However, a few samples belong to OI group, which is indicative of Organic silts of medium plasticity. The organic content in the soil may be because of the human activities like terrace cultivation, etc. which might have increased the porosity of the soil and decreased the shear strength of the soil. As a result during rainy seasons, when the natural water content is quite high, the chance of slope failure will be much more as the porosity of these organic soils is higher than the inorganic ones accommodating higher moisture quantity. Besides, the shear strength of these organic soils will also be lower than the inorganic soils and therefore more prone to slope failure.

Consistency Index values computed from the maximum water content indicate values less than 1 for majority of the soil, indicating that the value is very close to liquid limit state. Usual moisture contents of the soils are found to be greater than plastic limits, which indicate that soils are in plastic state during this period (Since the data have been collected after the rainy season the value of the maximum moisture content has been considered). Again since the rainfall duration is quite long in the state, the soils on the slope are in plastic limit for longer period of time. So, it is quite natural that these slopes fail during the monsoon period. Liquidity index and consistency index computed for these soils based on moisture contents indicate near critical values. Liquidity indices of these soils are more than zero (+ve), whereas the consistency indices are also less than 1 approaching zero which may become negative during rainy season when the moisture content is very high, indicating that the zone is in an unstable state.

b) Direct Shear test

The objective of direct shear test is to determine the shear strength of soil directly by allowing the sample to fail by shear in an instrument called shear box. Here, the soil is allowed to fail along a predetermined plane/surface, which is horizontal. The test is conducted for different values of normal stress.

Direct shear tests were carried out to ascertain the geotechnical properties of the soils. Direct shear tests were carried out for two landslide sites: Kisama and Viswema with a view to find out their shear strength parameters and geotechnical implications on the nature of the slope failure.

Kisama slide

Four samples K-1 to K-4 were collected and these were tested at different values of normal stress (σ) and the results obtained are shown in Table 7.1.e

Table 7.1e Normal and shear stress of Kisama landslide soils

Sample No	**Normal Stress (σ_n)** kN/m^2	**Shear Stress (τ)** kN/m^2	**Stress Ratio (τ/σ)**	**Water Content** %
K1	19.6	7.5	0.38	18.06
K2	39.2	14.72	0.37	17.77
K3	29.4	10.55	0.36	18.50
K4	49.0	16.11	0.33	22.16

Cohesion (C) = 2.0kN/m^2; Internal friction angle (φ) =16°

Interpretations

The results were plotted in a graph with Normal Stress (σ_n) as abscissa and Shear Stress (τ) as ordinate. A graph is drawn to obtain the Coulomb failure equation, $\tau=c+\sigma_n \tan\varphi$, and shown in Fig. 7.1g. From the figure it is found that the value of C of the soil is about 2.0kN/m^2, and φ = 16°.

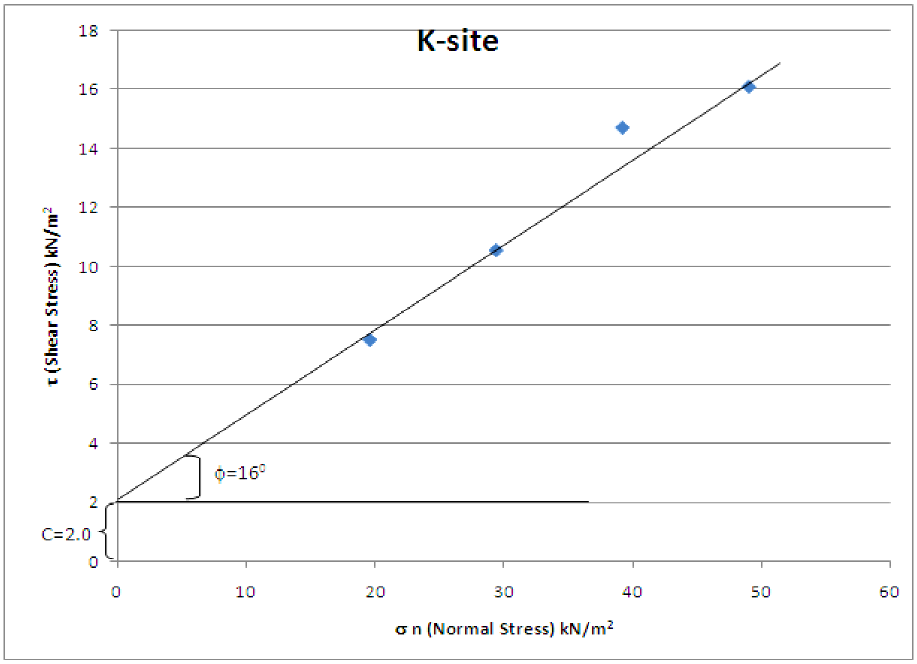
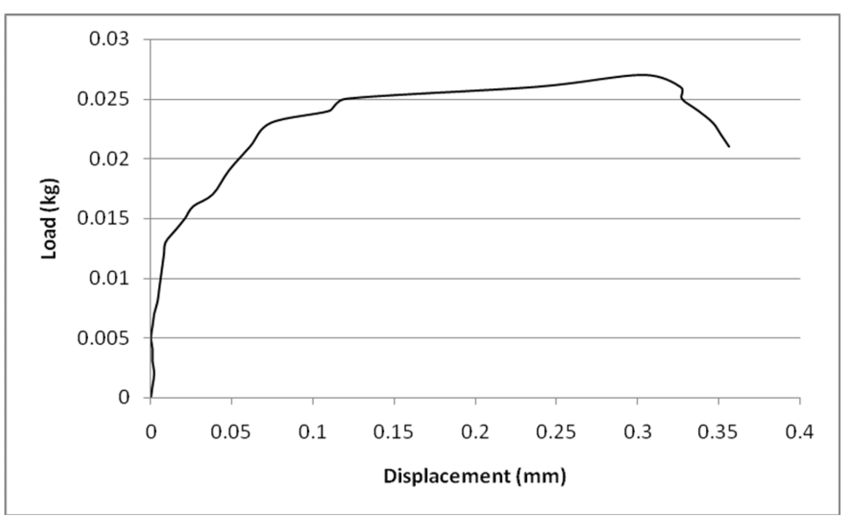


Fig. 7.1g Plots of normal and shear stresses for Kisama landslide soils

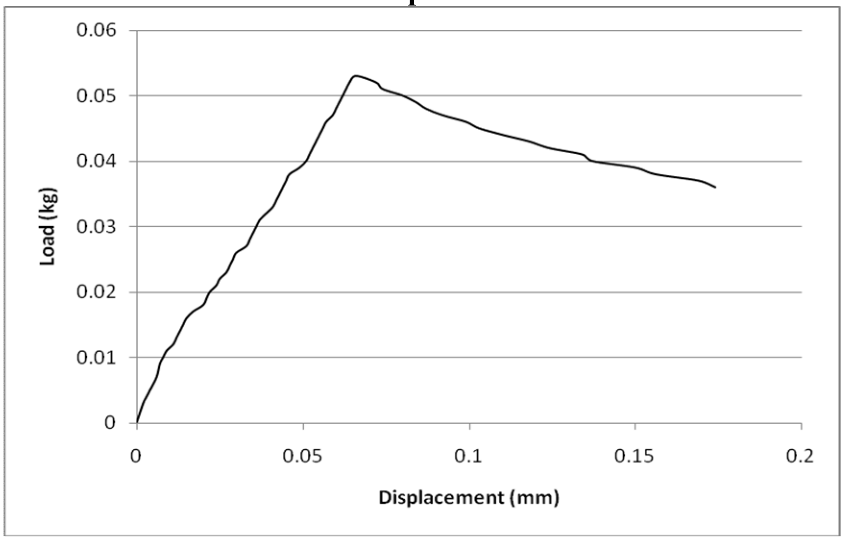
In order to determine the geotechnical nature and behavior of these soils the stress and strain, i.e., load and displacement curves of the four samples (K1, K2, K3 and K4) are also plotted and shown in Figs. 7.1h. From the graphs it appears that these soils are mainly clay with some amount of silt and sand; sample K1 has a larger quantity of clay.

Fig. 7.1h Stress and strain curves of the Kisama landslide soils

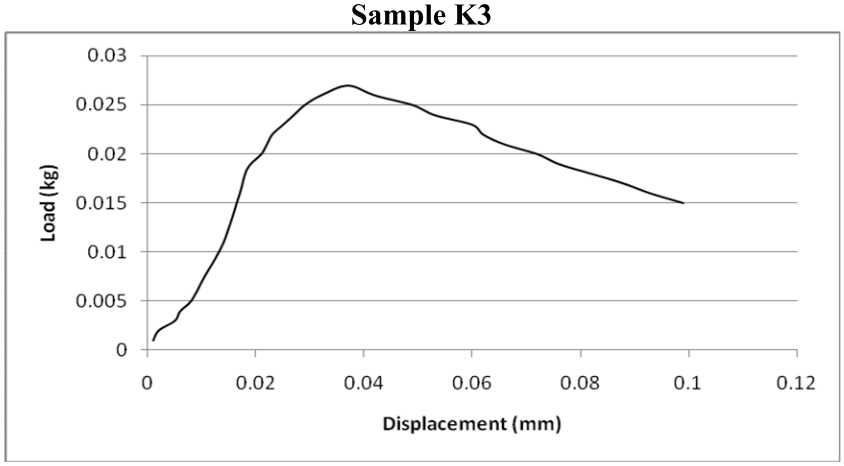
Sample K1



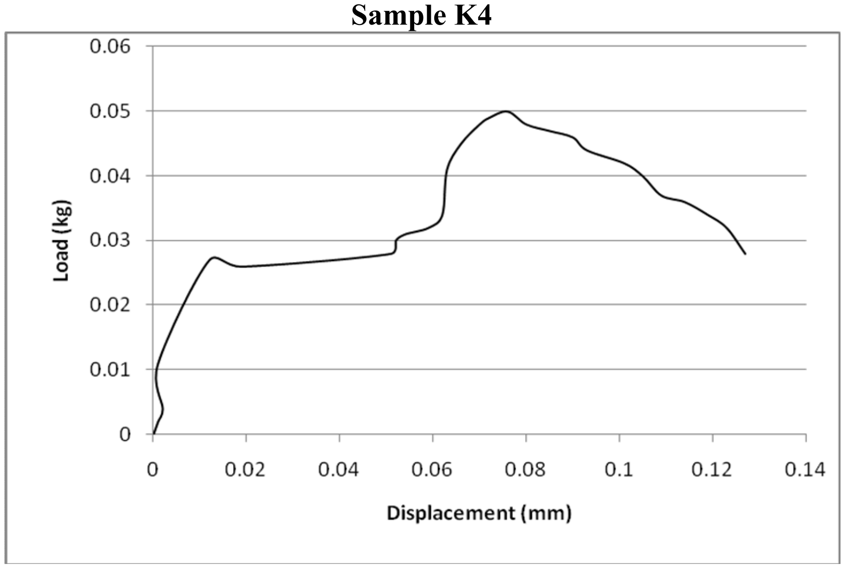
Sample K2



Sample K3



Sample K4



The cohesive strength (C) and internal friction angle are low, which means that these clayey soils may have some percentage of silt and fine sand. The values of cohesion and internal friction are 2.0 kN/m^2 and 16° respectively. Hence, slopes cut greater than the internal friction angle will, virtually be, unstable. Hence, landslides will be common if slope cuts are greater than 16° in these areas.

7.1.5 Recommendations

1. The inclination of the slope should be reduced. Benching can be done to minimize the load at the head with geo-jute covering.
2. No construction around the crown area.
3. Construction of a strong breast wall with weep holes to be extended through the entire length of the affected area.
4. Surface runoff should be effectively channelized via a good roadside drain to check seepage into the subsurface.
5. The Hume pipe that drains subsurface run-off in the study area should be re-routed to avoid draining into the slide area.
6. The high tension power line should be immediately relocated.
7. Surface erosion must be controlled by shotcreting on the slope surface below the road.
8. Strong concrete cribbing on the toe of the slide with the foundation anchored firmly on the bedrock.

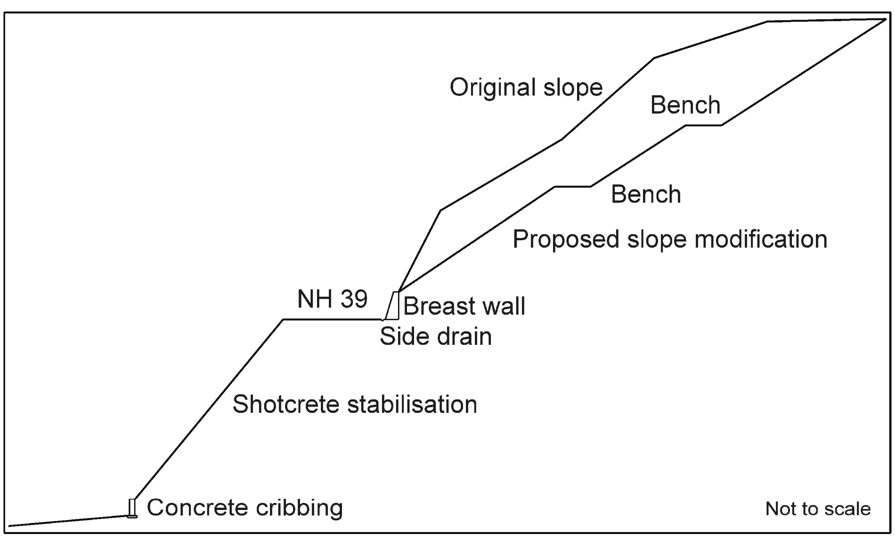


Fig. 7.1.1a Proposed mitigation measure

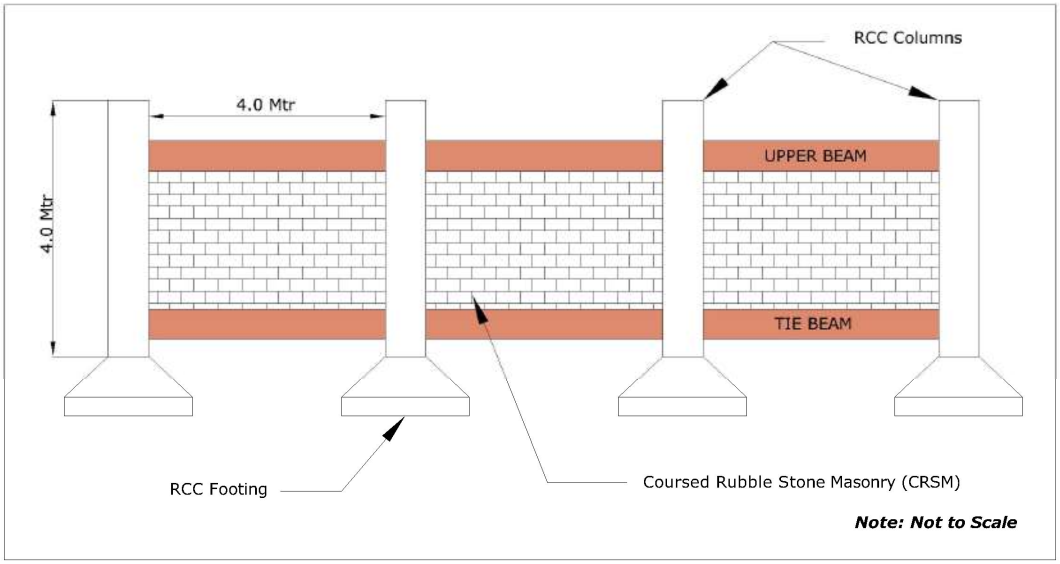


Fig. 7.1.1b Proposed concrete crib wall

7.2 LOCATION 2- VISWEMA SLIDE

Introduction

Investigations are carried out in this area to ascertain the factors responsible for the instability. This zone is situated along the NH 39 and is located at 25°33’40.29” and 25°34’25.01” N latitudes and 94°8’21.31” & 94°8’45.29”E longitudes. This is a very unstable area that was activated in the early 1960’s and has continued to pose problems till date. Instances of highway blockage in the past have disrupted communication between Kohima and Imphal. The length of the active slide zone is about 1200m while the breadth is about 440m covering an area of 408139.48 sq m (Fig. 7.2). It affected the highway for a length of about 130m. The highway is constantly being worked on by the BRO to keep it functional. Retaining walls are also continuously being erected. However, they do not last long as the foundations of the walls are constructed within the slide debris (Plate 7.2.a). The drains constructed are shallow and ill maintained. Hence, they allow abundant water to percolate into the subsurface. The slide is also affecting the state highway which is located immediately below the national highway (Plate 7.2.b).

7.2.1 Geology and structure

Bedrocks are not exposed in the affected area but nearby outcrops show the presence of Barail sandstone with thin beds of shale. The area shows a lot of debris with black and brown shales and clays. They are highly sheared. The sandstones exposed in some

Plate7.2.a Foundations of retaining wall on slide debris

Plate 7.2.b Affected State Highway

places show brown color due to iron oxidation (Plate 7.2.1). These rocks are highly crumpled and exhibit two prominent sets of joints such as 50°→135° and 45°→350°. A NE-SW trending lineament cuts through across the area.

7.2.2 Causes and effects

Studies have revealed that a number of factors are responsible for the failure of the slope. It is observed that the fault running through the area have sheared the rocks to a high degree making them friable and weak and highly susceptible to weathering. The intense fracturing and crumpling of the rocks of the area may be due to ongoing movements along the fault. The weathered products of these rocks, the black and brown clays, are very weak and are already in a liquid limit state. The region received abnormally high rainfall during 2007 (Table 1.1), the year the slide took place. The waters that percolate into the subsurface from the poorly vegetated surface are trapped underground in the zone of the poorly permeable clays where terrace cultivation is practised on the lower portion of the slide area. This caused the clay minerals in the shale to bulge leading to water logging. This in turn puts tremendous pressure on the soils by increasing the pore pressure.

These factors together had caused a large section of the road to be washed away (Plate 7.2.2.a). This was a warning sign that went unheeded and ultimately led to the massive devastation where all the terrace fields of the village were destroyed. The process also leads to overflow of water, debris, and mud. Loss of frictional resistance due to excess moisture had lead to reduction of shearing strength and resulted in a devastating landslide. The area remains damp and marshy throughout the year due to a very shallow water table. On the lower reaches of the slope a road leads to the village located immediately below the highway. The slope had been cut and modified for construction of road but it needs careful monitoring as it is severely affected. It is no longer motorable as part of the road is gone. The fault traversing the area, unfavourable fresh-cut slopes, the terrace cultivation and the intense water together caused instability in the area.

Plate 7.2.1 Highly oxidised sandstone

Plate 7.2.2.a Road section affected by landslide

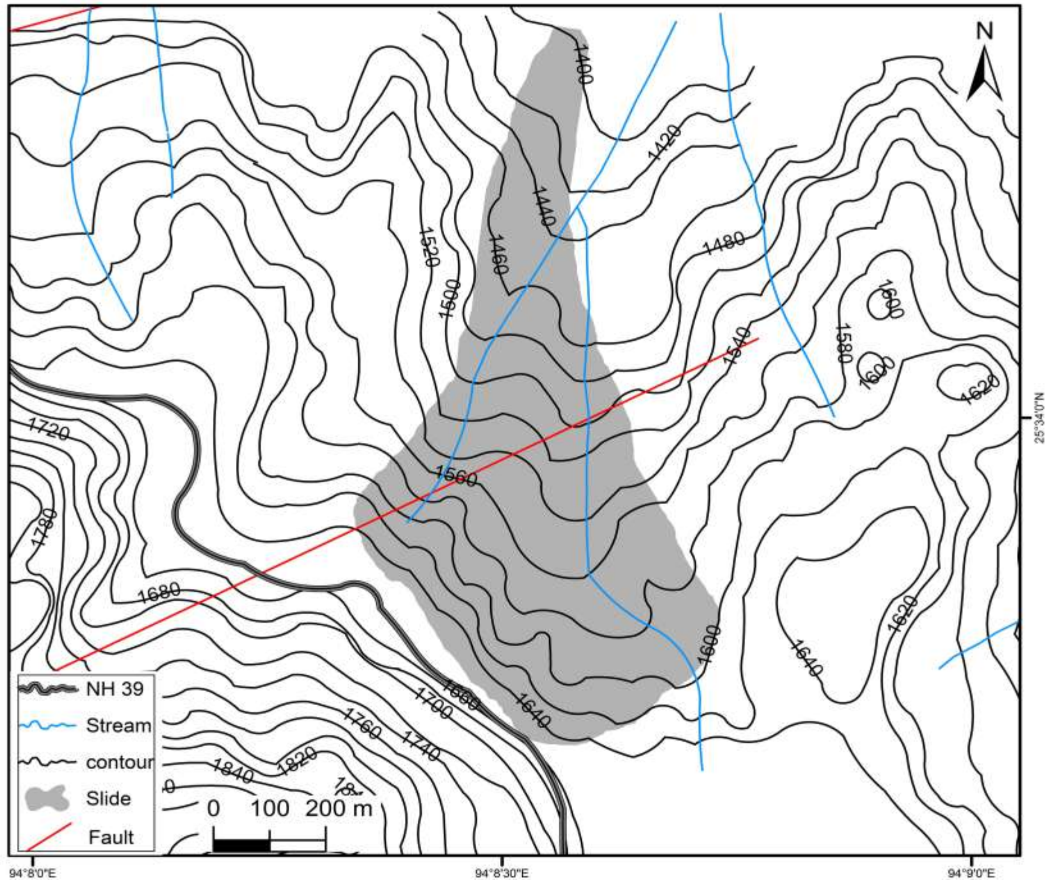


Fig. 7.2 Location map

Another factor, though minor in the larger context, leading to the present creep is the poor drainage system. This area also has a high concentration of subsurface water due to the inherent nature of the shale and its weathered product (Plate 7.2.2.b). Part of the area appears to be under control however, the zone is very weak indicated by the often collapsing of the retaining wall on the highway. Adequate preventive measures should be provided.

7.2.3 SMR and Kinematic analyses

a) SMR

Forty five rock samples were collected from the site to determine their strengths. Point load test data indicates low value for the rocks (Table 7.2). RMR values of 34 indicate fair stable rocks. SMR values fall in Class IV, which indicates partially stable slope conditions that requires systematic maintenance.

Table 7.2 Slope mass rating

	Value or Condition	Rating
1. Point Load Test	2.2 MPa	7
2. RQD	16	3
3. Spacing of joints	33 mm	5
4. Condition of joints	Slightly rough; separation <1 mm; soft joint wall rock	12
5. Groundwater condition	Moist	7
RMR	*(1+2+3+4+5)*	***34***
6. $F_1 = (1\text{-Sin}I\alpha_j - \alpha_s I)^2$	35°	0.15
7. $F_2 = \text{Tan}^2\beta_j$ or $F_2 = 1$ for toppling	45°	1.00
8. $F_3 = I\beta_j - \beta_s I$ for plane failure $= I\beta_j + \beta_s I$ for toppling	-5°	-50
9. F_4 = Adjustment factor	Pre-splitting	10
SMR *= RMR+(F₁xF₂xF₃)+F₄*	*34+{0.15x1.00x(-50)}+10*	***36.5***
10. Class	IV	
11. Description	Unstable	

b) Kinematic analyses

Kinematic analyses have been performed from 200 joint attitudes taken in the field to determine the probable mode of failure. From joint analyses, pole density (Fig. 7.2a) and contour diagrams (Fig. 7.2b) are constructed and from which two dominant joint sets are identified. These are plotted against slope attitude in a stereographic projection (Fig. 7.2c).

J_1 : 50°→135°

J_2 : 45°→350°

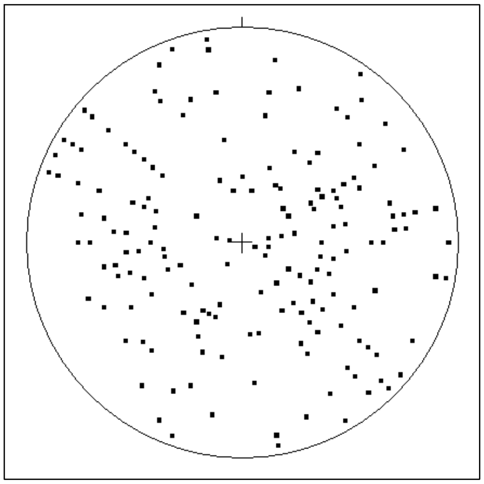


Fig. 7.2a Pole diagram

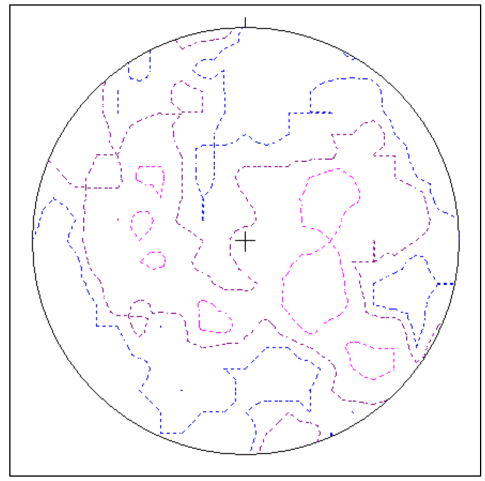


Fig. 7.2b Contour diagram

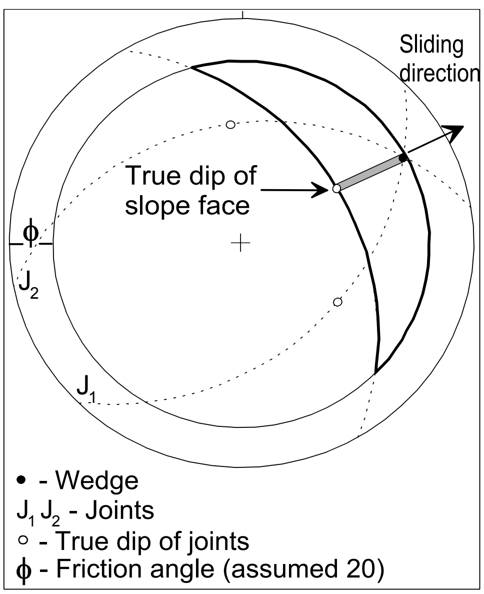


Fig. 7.2c. Stereogram

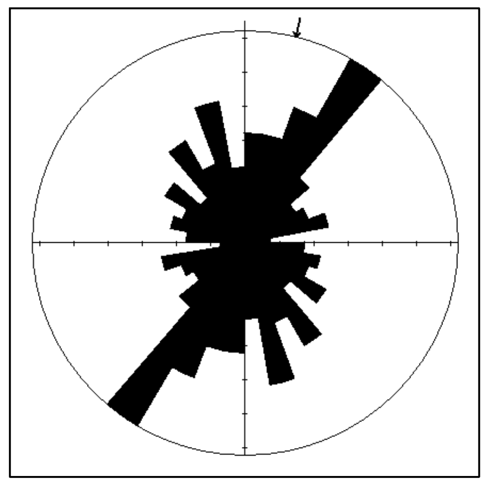


Fig. 7.2d. Rosette

These joints are plotted against slope attitude in a stereographic projection (Fig.7.2c). The diagram shows a distinct wedge due to the intersection of joints J1 and J2. Cruden (1978) suggests double-plane wedge failure in such cases as both the true dips of the two joints lie outside the shaded area. The rosette of this location shows that the lineaments are in conformity with that of the general trend of the region that is affected by F_1 folds. The rocks are also faulted along this plane (Fig.7.2d). Antithetic and synthetic shearing stresses have also played a role in rock deformation.

7.2.4 Geotechnical analysis of soils and Direct Shear Test

a) Geotechnical analysis of soil

Soil samples were collected from the landslide affected area (V_1, V_2, V_3).One sample each was collected from the adjoining stable area (V_4). A series of laboratory tests were carried out to ascertain the geotechnical properties of these soils.

Table7.2a Data and observation sheet for liquid limit determination

Sample No. V1

Container No	**1**	**2**	**3**	**4**
Weight of container (g)	6.29	9.33	9.82	9.49
No of blows	19	15	30	24
Weight of container + wet soil (g)	27.22	32.02	35.34	31.13
Weight of container+dry soil (g)	20.40	24.55	27.33	24.31
Water content (%)	48.33	49.08	45.74	46.02
Liquid limit (W_L) = 46.5 % *Flow index (I_f) = 23.5 %*				

Sample No. V2

Container No	**5**	**6**	**7**	**8**
Weight of container (g)	9.10	6.35	6.14	6.46
No of blows	21	15	33	22
Weight of container + wet soil (g)	38.67	38.56	38.05	34.21
Weight of container + dry soil (g)	30.41	29.47	29.31	26.47
Water content (%)	38.76	39.32	37.72	38.73
Liquid limit (W_L) = 38 % *Flow index (I_f) = 10 %*				

Sample No. V3

Container No	**9**	**10**	**11**	**12**
Weight of container (g)	14.35	9.31	9.85	9.46
No of blows	32	23	31	24
Weight of container + wet soil (g)	45.36	36.02	35.55	37.20
Weight of container + dry soil (g)	36.74	28.44	28.35	29.31
Water content (%)	38.49	39.62	38.92	39.74
Liquid limit (W_L) = 39.5 % *Flow index (I_f) = 14 %*				

Sample No. V4

Container No	**13**	**14**	**15**	**16**
Weight of container (g)	6.09	5.90	9.31	9.55
No of blows	28	22	17	30
Weight of container + wet soil (g)	27.23	23.60	30.59	30.20

Weight of container + dry soil (g)	19.64	17.15	22.68	22.90
Water content (%)	56.01	57.33	59.16	54.68
Liquid limit (W_L) = 56.5 % *Flow index (I_f) = 26 %*				

Table7.2b Data and observation sheet for plastic limit determination

Sample No. V1

Container No	**1**	**2**	**3**
Weight of container (g)	9.49	14.35	12.51
Weight of container + wet soil (g)	10.33	15.48	13.44
Weight of container + dry soil (g)	10.14	15.25	13.24
Water content (%)	29.23	29.88	27.39
Average water content (W_P) =28.83 %			

Sample No. V2

Container No	**4**	**5**	**6**
Weight of container (g)	9.13	9.65	5.90
Weight of container + wet soil (g)	10.08	11.06	6.50
Weight of container + dry soil (g)	9.93	10.82	6.40
Water content (%)	18.75	20.51	20.00
Average water content (W_P) =19.75 %			

Sample No. V3

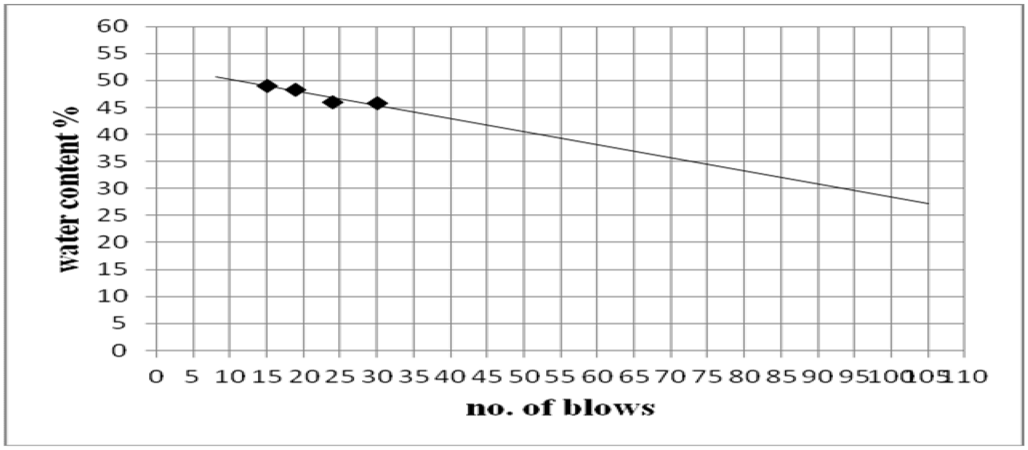
Container No	**7**	**8**	**9**
Weight of container (g)	9.65	9.33	9.82
Weight of container + wet soil (g)	11.30	10.10	10.74
Weight of container + dry soil (g)	11.01	9.97	10.58
Water content (%)	21.32	20.31	21.05
Average water content (W_P) = 20.89 %			

Sample No. V4

Container No	**10**	**11**	**12**
Weight of container (g)	9.55	5.90	9.33
Weight of container + wet soil (g)	10.43	6.55	10.42
Weight of container + dry soil (g)	10.27	6.45	10.21
Water content (%)	22.22	22.64	23.86
Average water content (W_P) =22.90 %			

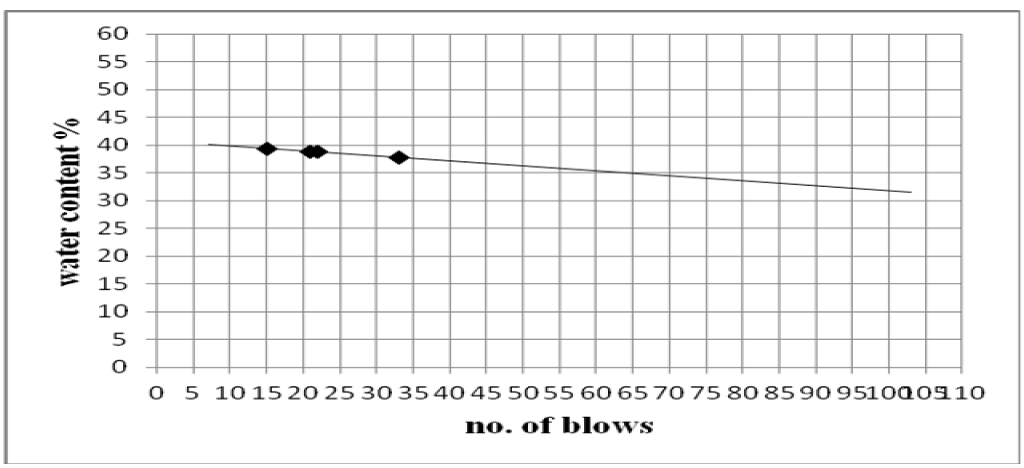
Figure 7.2e Liquid limit graph

Sample No. V1



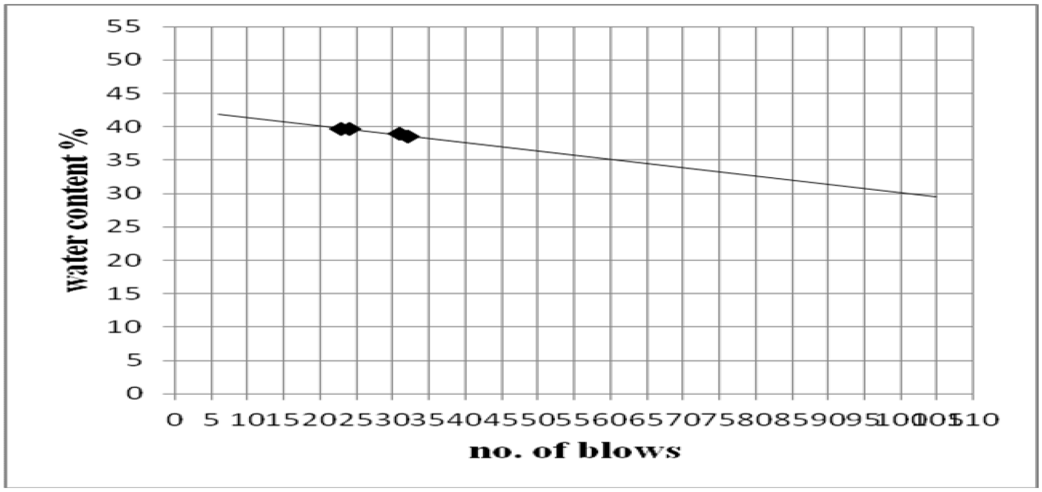
No. of blows	19	15	30	24
Water content	48.33	49.08	45.74	46.02

Sample No. V2



No. of blows	21	15	33	22
Water content	38.76	39.32	37.72	38.73

Sample No. V3



No. of blows	21	15	33	22
Water content	38.76	39.32	37.72	38.73

Sample No. V4

No. of blows	28	22	17	30
Water content	56.01	57.33	59.16	54.68

Table7.2c Data and observation sheet for shrinkage factor

Sample No	**V1**	**V2**	**V3**	**V4**
Container no	**5**	**6**	**7**	**8**
(a) Water content of wetsoil				
1. Weight of shrinkage dish (g)	6.57	6.36	6.22	5.98
2. Weight of shrinkage dish+wet soil pat (g)	40.15	43.27	38.42	38.35
3. Weight of shrinkage dish+dry soil pat (g)	27.68	31.12	27.63	26.13
4. Weight of dry soil pat (W_0) (g)	21.11	24.76	21.41	20.15
5. Weight of wet soil pat (W) (g)	40.15	43.27	38.42	38.35
6. Moisture content (M) (%)	59.07	49.07	50.39	60.64
(b) Volume of wet soil pat				
7. Volume of mercury or volume of wet soil pat in ml (V)	319.73	334.89	300.70	314.07
(c) Volume of dry soil pat				
8. Volume of mercury displaced by dry soil pat in ml (V_0)	197.72	199.03	191.23	194.34
9. Shrinkage Limit (S_L) (%)	16.58	8.73	12.80	16.92
10. Shrinkage Ratio (S_R)(%)	1.80	2.10	1.91	1.76
11. Volumetric Shrinkage (V_S) (%)	76.48	84.71	71.79	76.94

Table 7.2d Consistency limit Determination of soil samples from Viswema Slide

Sample No.	Natural water content	Plastic Limit (W_P) %	Liquid Limit (W_L) %	Plasticity Index (I_P) %	* Liquidity Index (I_L) %	* Consistency Index (I_C) %	Flow Index (I_f) %	Toughness Index (I_T) %	Shrinkage Limit (S_L) %	Shrinkage Ratio (SR) %	Volumetric Shrinkage (V_S) %
V1	26.42	28.83	46.50	17.67	1.00	0.00	23.50	0.75	16.58	1.80	76.48
V2	46.43	19.75	38	18.25	1.46	-0.46	10	1.83	8.73	2.1	84.71
V3	17.99	20.89	39.50	18.61	1.37	-0.37	14	1.33	12.8	1.91	71.79
V4	19.74	22.90	56.5	33.6	0.70	0.30	26	1.29	16.92	1.76	76.94

* *Values calculated with highest natural water content*

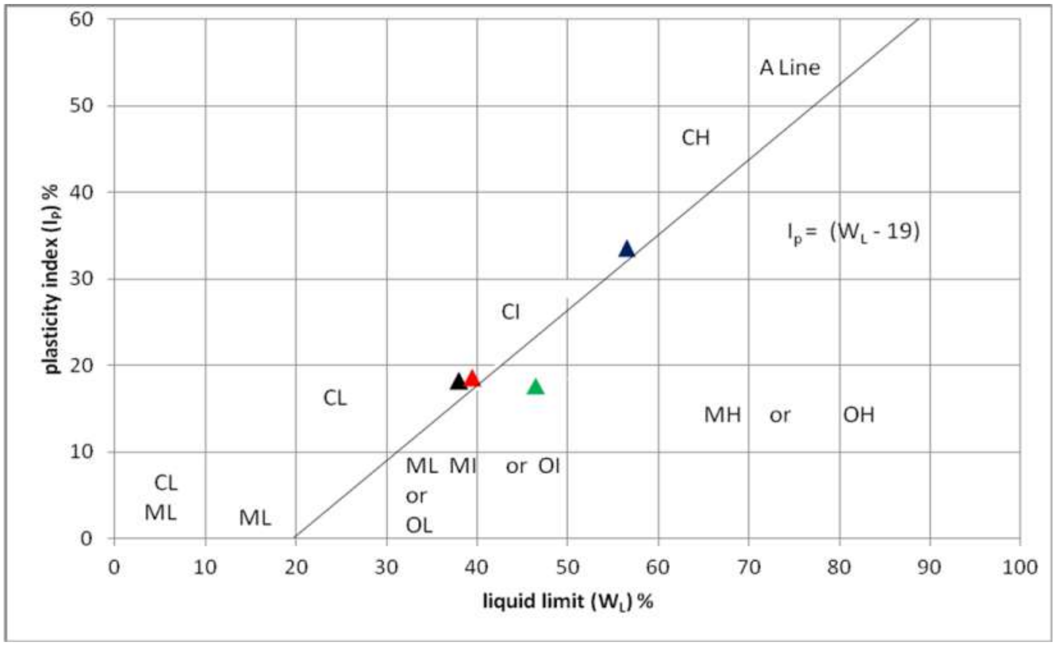


Fig. 7.2f Plasticity chart for soils of Viswema slide (IS: 1498-1970)

Liquid limit (W_L)	46.5	38	39.5	56.5
Plasticity index (I_p)	17.67	18.25	18.61	33.6

In order to understand the firmness of the soils, consistency limits of the slide area are given in (Table 7.2d). Plasticity chart prepared for the soils indicate that soil samples falls under OI group, which is indicative of organic silts of medium plasticity and also falls between CI and MI group, depicting that the soils are inorganic clays of moderate plasticity and inorganic silts of medium plasticity.

Consistency Index values computed from the maximum water content indicate values less than 0 (-ve) indicating it to be in liquid state, failure. Moisture content of the soils are found to be greater than liquid limit, which indicates that soils are already in liquid state failure (Since the data has been collected after the rainy season the value of the maximum moisture content has been considered). So with or without more water in the area the zone is bound to give way. So, it is expected that these slopes fails anytime of the year becoming more unstable during the prolonged rainy season. Liquidity indices of these soils are more than zero indicating that the zone is in an unstable state.

Direct shear test

For Viswema landslide also, similarly, four samples (V-1 to V-4) were collected and subjected to direct shear tests under different values of normal stresses. The results obtained for these tests are shown in Table 7.2.e

Table 7.2e Normal and shear stress of Viswema landslide soils

Sample No	**Normal Stress (σ_n)** kN/m^2	**Shear Stress (τ)** kN/m^2	**Stress Ratio (τ/σ)**	**Water Content** %
V1	9.8	10.83	1.11	26.80
V2	19.6	12.78	0.65	20.89
V3	29.4	15.27	0.52	26.81
V4	39.2	16.11	0.41	21.19

Cohesion (C) = 8.54kN/m^2; Internal friction angle (φ) =13°

As C as well as φ are low, these could be clay with a little fine silt. Slope cuts more than internal friction angle will, therefore, be not stable.

The results of these tests are plotted in a graph where Normal Stress (σ_n) is plotted as the abscissa and the Shear Stress (τ) as the ordinate. A best fit line is drawn to give the Coulomb's failure equation, $\tau = c + \sigma_n \tan\varphi$, and shown in Fig. 7.2g.

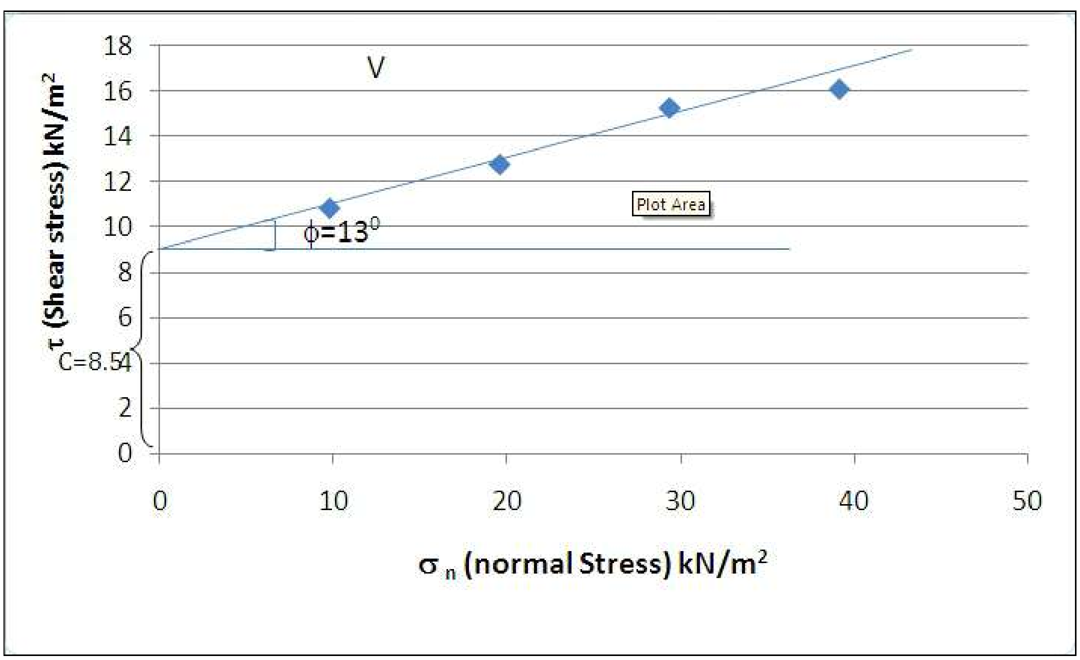


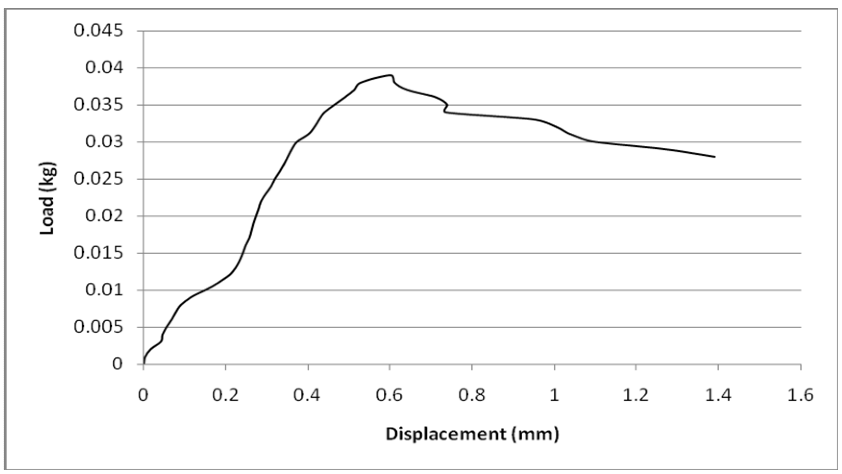
Fig. 7.2g Plot of normal stress and shear stress for Viswema landslide soils

From the figure it is found that the value of cohesion of the soil is about 8.5kN/m^2, and the internal friction angle = 13°.

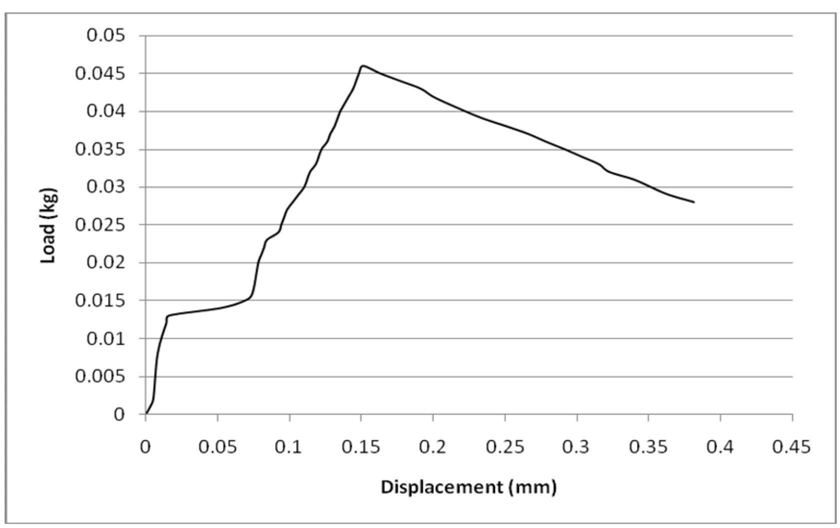
In order to determine the geotechnical nature and behavior of these soils, the stress and strain, that is, load and displacement curves of the four samples (V1, V2, V3 and V4) are also plotted and shown in figure 7.2h. From the graphs it appears that these soils are mainly clay with some amount of silt and sand.All the samples have a good amount of clay except for sample V1 which has some amount of silt and sand.

Fig. 7.2b Stress and strain curves of the Viswema landslide soils

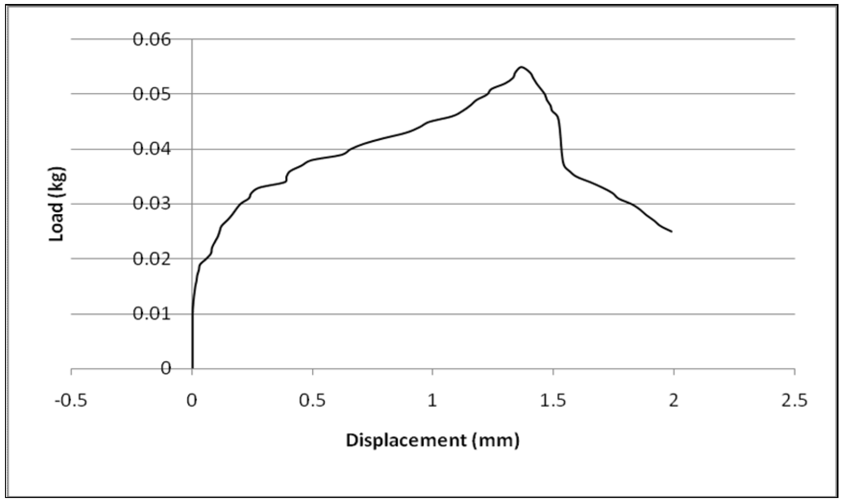
Sample V1



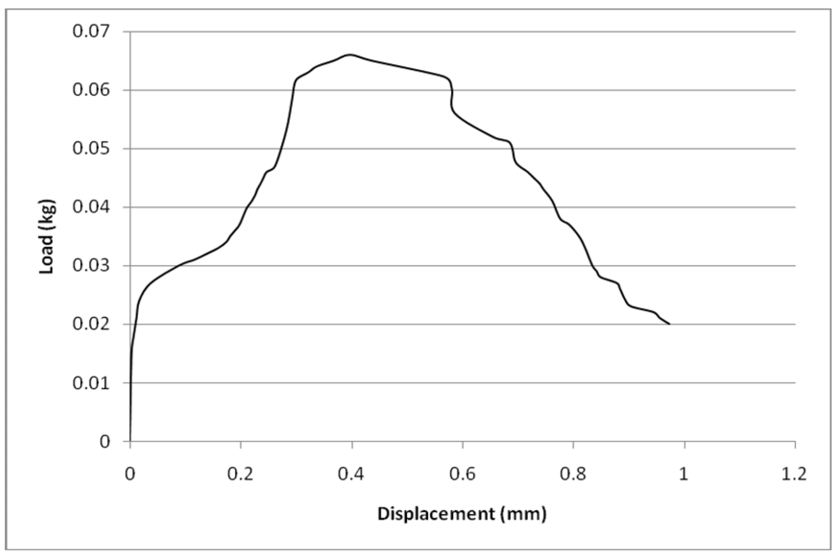
Sample V2



Sample V3



Sample V4



Interpretation

The cohesive strengths and internal friction angles are low, which may be due to the presence of clay and minor silt and fine sand. The value of C is 8.54kN/m^2 while φ is 13°. So slope cuts more than the internal friction angle will, virtually be, unstable. That is, landslides will be common if the slope cuts are more than 13° in these areas.

7.2.5 Recommendations

1. Logically thinking, marginal stabilization might be the best solution for this slide zone because of the large size and/or high cost of standard stabilization. A lower 'margin of stability' could be considered in an attempt to reduce the hazard level. If a "Marginal Stabilization" approach is adopted, mitigation measures could be applied in phases until the desired reduction in movement is accomplished.
2. Wide gap should be maintained between two roads.
3. A counterfort wall with a height of 3 m and length of 30 m along the road is recommended.
4. Drainage of subsurface water through perforated pipes is necessary to prevent buildup of pore pressure.
5. Deep roadside drain with the road tilting towards the drain to prevent water logging and also the drain should be routed away from the slide area.
6. A short term and low cost alternative is hydro-seeding the slope, a process which utilizes a slurry of seed to control further erosion and prevent subsurface seepage. This slurry sprayed over the prepared surface of the slide area help in the germination of plants and thereby stabilizes the area to some extent.
7. *Vetiver* grass hedgerows are effective in tropical and subtropical areas because of their fast growth and deep root penetration (Yoon, 1995a, b).
8. Though expensive, cement grouting of sub-surface along the entire slide area.

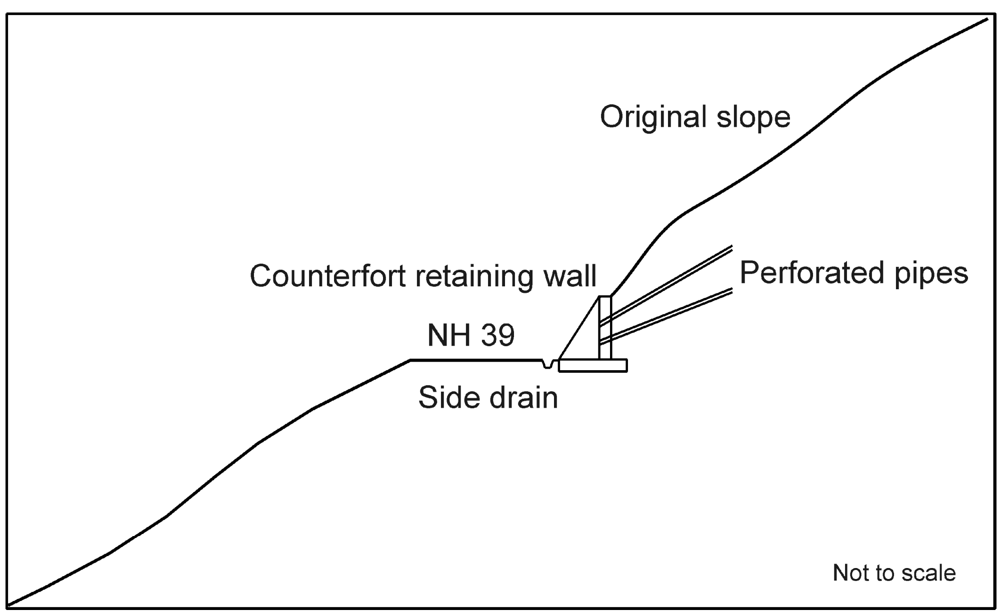


Fig.7.2.1a Proposed mitigation measure

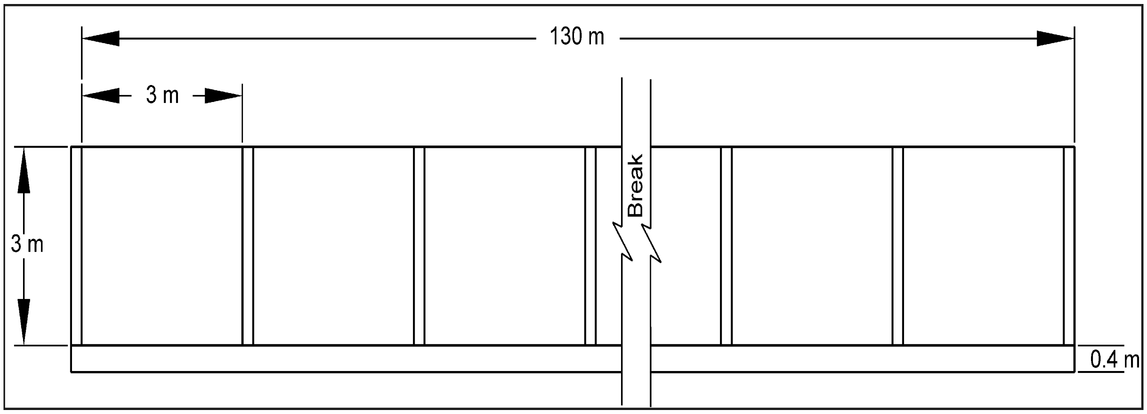


Fig.7.2.1b Front elevation of proposed counterfort wall

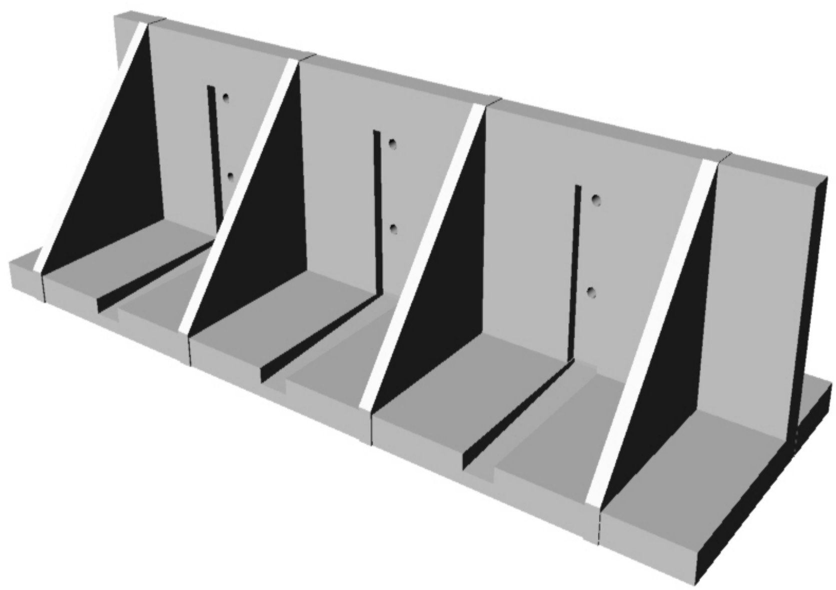


Fig.7.2.1c 3D model of counterfort wall

CHAPTER 8

DISCUSSION AND CONCLUSIONS

8.1 DISCUSSION

India is a unified country of diverse physiographic and climatologic conditions that faces different natural hazards frequently. In the midst of different disasters our country faces, landslide is one major natural hazard, with which a considerable area of the country has to challenge with, achieving to at least 15 percent of the land area, an area that exceeds 0.49 million km^2 (National Institute of Disaster Management, 2009). The Himalayas and the northeastern hill ranges goes through considerable landslide of varying intensities in the process causing large scale casualties and huge economic losses. (Naithani, 1999) stated that besides causing more than 200 deaths every year, which overall is considered 30% of such type of losses occurring worldwide, it has been predicted that, the damage caused by landslides in the Himalayan ranges alone costs more than US $1 billion.

When an area is to be developed or an infrastructure to be constructed in probable or identified landslide areas, the planned area has to be thoroughly studied and risks appraised to establish whether adequate firmness can be achieved in the course of mitigation or stabilization method. So studies should absorb detailed field investigations for geology, soils, hydrology, topography, rainfall and human factors, which collectively cause slope instability, and geotechnical analyses and monitoring of selected landslides. Studies may wrap up with recommendations for methods and procedures for mitigation of existing landslides.

About 90 percent of Nagaland state is ornamented with hills and for the most part the rocks are highly deformed due to under-thrusting of the Indian plate below the Burmese plate. These deformations are distinct in the form of folding, faulting, shearing and a number of jointing (Plate 8.1.a). Also rapid weathering continues to damage the already weakened rocks as the region receives abundant rainfall. All these factors together add a major role in generating instability in the study area or the region as a whole.

Plate 7.2.2.b Concentration of sub-surface water

Plate 8.1.a Joints in Sandstone

Landslides are regular and repeated incident with the onset of monsoon in this region, which receives heavy rainfall. It has contributed a huge threat to the people living in this area, particularly during ceaseless rains. Every year landslides create huge hurdles especially in road communications. During this time of the year, traffic along this highway often gets disrupted not only for few hours, a day or two but sometimes more than a week.

The study area is embraced by jagged hills of Upper Cretaceous-Eocene argillaceous sediments of the Disang Group and some younger arenaceous Barail of Oligocene age. They show signs of concretionary structures and box-work weathering. They are also highly jointed, folded, and faulted. The Disang rocks are mostly shales with well bedded siltstones and sandstones. Reddish brown colouration is noted in places due to leaching of iron oxide (Plate 8.1.b). Common characteristic features of rich organic matter which are dark grey and black shales gets weathered to clays. On contact with water these clays turn greasy and perform as a lubricant which increases the pore-water pressure leading to inter grain friction. This exhibits loss in their shearing strength and soil structure finally gives way. The study location is along the area where the shales are highly creased and fissile due to which, on exposure to air, they disintegrate and weather easily. When saturated, they start flowing to cause debris and mud flows. The Barail rocks of the area displays thick beds of sandstones with thin intercalation of shale beds. The failing factors are added by the highly jointed and sheared sandstone beds noted along steep bedding or joint planes (Plate 8.1.c). Also the shales with their weak planes have a trend to cause rockslides.

This study tried to bring about a spatial discrepancy of slope failure probability of the area. Whereby, it becomes obligatory to find out the main cause considering the geomorphology, geological features, human interventions, rainfall, earthquakes, land use / land cover and other associated parameters. While Geo-environmental aspects were derived from different sources through the analysis of topographic maps and satellite imagery (IRS-P6 PAN) including GPS data to deal with the required objective. They are then imputed into the digital format in ArcGIS 9.2 and finally remarkable data bases created for road network, facet, slope angle, land use / land cover, drainage network, lithology, structure, relative relief and landslide incidences engaging visual interpretation and digital modus operandi.

Plate 8.1.b Leaching of Iron oxide

Plate 8.1.c Rock Fall

Basing on their degree of influence special standards has been assigned in causing landslides. The Bureau of Indian Standards (1998) did recommend rating of 2.0 for lithology but in the area instability is observed even in gentle slopes owing to local steepness of the slopes and the weak rocks and soils. For this reason, it was reasonable to upgrade the rating of lithology for this area to 2.5 from the recommended value. Correspondingly, the rating for land use / land cover is reduced to 1.5 from 2.0 as the relative effect of this factor is not as noteworthy as that of lithology. Other rating values for the different classes remain unchanged. The total rating type on these factors is 10, and based on this total value the TEHD is calculated. Therefore, linked to the computed TEHD values susceptible zones were categorized into five categories, viz., very low, low, moderate, high and very high.

In the study area a good number of slopes are mapped as gentle but to a large point these are locally moderate to steep particularly along stream channels as they are really too small to be classified as individual facets. Hence, by and large the ratings of the general slope of that facet were specified. All the five different groups of slopes were recognized in the study area. With relation to that, 54.54% are under gentle slopes, 40.91% moderately steep slopes and 4.55% as steep slopes. Moderately steep slopes show rationally high values whereas the frequency of landslides on the gentle slopes is also high. Slides normally occur in areas of locally steep slopes but in some areas it occurs in gentle slopes too, mainly because in such areas terrace cultivation were practiced. Water stored in paddy fields induces landslides. The reason is due to greatly increased pore-water pressure generated on the soils due to retention of large amounts of water for the paddy plants. It has also been identified that most of the area under terrace cultivation are actually palaeoslide zones. Though slope triggers landslide, structures and the material making up a slope decides to a great extent whether a slope will fail or remain stable. The allocation above indicates that the structures of the area and the material making up the slope can also be contributory and controlling factors of instability and that slope as thought is also not only a dominant factor.

In the case of relative relief, 31.82% of the slides occur in low relief and 68.18% occur in the moderate relief areas. This is probably because the highway has been cut across areas of low and moderate relief in relation to the steepness of the area.

Plate 8.1.d Debris Slide along the Highway

Plate 8.1.e Landslide inside the village

The lithological map of the study area shows varied litho-units. About 36.36% of the slides occur in loose debris and 18.18% in partially loose debris, 27.27% in weathered shale and 4.55% in partially weathered and crumpled shale and 9.09% in shale with minor sandstone. The other litho-units are more stable and not affected by landslides. Incidences of slide are more in loose debris and partially loose debris (Plate 8.1.d). This is because debris slopes are often mixed with clays which have generally low shearing strengths and rumples easily with the presence of water. Weathered horizons and partially weathered horizon show high frequency of slides the reason being continuous rainfall during the monsoon where the shearing strengths of clays are reduced. The frequency of slides in the crumpled shale and shale with minor sandstone also submit to the same grounds rendering to rampant slope cutting.

Majority of the study area depicts damp condition owing to the reason that the water table of the area is quite low and any amount of additional water can bring about instability in the area. The largest percentage of slides occurred in dripping areas (63.64%) followed by the damp areas (18.18%).The wet area shows (13.64%) of landslides. However, the frequency of landslides in flowing areas (4.55%) is low as their contributing action in the area is less and they occupy only a small section in the division.

Land use / land cover has been conveniently classified into five categories. Some small villages are positioned in geologically uneven areas and as such these areas suffer constant landslide (Plate 8.1.e). Furthermore, haphazard earth cutting and unscientific land use practices for construction of large and heavy structures results in instability. A large amount of wet cultivation for paddy is interconnected to old landslides as the water retention during the growing season increases the pore-water pressure continuously resulting to subsidence and/or damage to hill slopes and roads. In the lightly vegetated areas, the soils are usually lean and lack cohesiveness and hence do not sustain flourishing plant life. Such areas are normally prone to landsliding and have been involved in about 50% of landslides. It is observed that moderately vegetated areas are also affected by landslides owing their cause to structural disturbances and weak lithology.

The study area has been demarcated into four LHZ classes. The map consists of low, moderate, high and very high hazard zones. The low and moderate hazard zones are free of landslides. About 31.82% are in the high hazard zones whereas 68.18% are in the very high hazard zones. Very high hazard zones have a frequency of 2.57% and high hazard zones 0.76% indicating that very high hazard zones are highly unstable. The high hazard zones are unstable too. Great deal of the area coming under moderate hazard zones is more or less stable as long as outside causes like large earthquakes, cloudbursts, excessive anthropogenic activity, etc., do not disturb the balance.

On studying the satellite imagery of the area, well-defined lineaments were identified. A number of deep channel have dissected the hill slopes. It is identified that steep gullies have formed owing to base erosion by streams cutting along fault planes. This example shows structural control where the lower order streams generally follow major joint patterns. Dendritic drainage pattern is common in the study area.

The tectonic disturbances in the area are reflected by numerous faults, folds riddled by a number of joints and fractures (Plate 8.1.f). Joint data which has been plotted in a rose diagram show majority of the lineaments in a NE-SW direction, which is essentially parallel to the regional trend. An additional set of joint trends NW-SE which owes its origin to tensile or shear stresses similar to antithetic and synthetic shear faults that are concentrated around the regional NW-SE compression. Due to contact of these stresses it generated hybrid fractures in the territory causing widespread deformation of the rocks. Rock falls are also dominant in vertical rock faces related to relief of the area coupled with road cutting. The shales are extremely fissile due to presence of anoxic waters (Curtis, 1980). The fissility coupled with the joint planes, have made this regions highly susceptible to mass wasting. These zones encompass varied materials that are thoroughly mixed with clayey, silty and sandy soils.

Bringing to a close in this study the chief reason following the factors of instability in the area is excessive rainfall received during the monsoon and anthropogenic activity. Meusburger and Alewell (2008) proved that there was an accelerating increase of 92% in landslide activity due to anthropogenic and environmental factors during a 45-year period (1959-2004) in the Central Swiss Alps.The study area too experiences prolong monsoon that continues for several months.Cloudbursts a very common phenomena in this region is a heavy downpour that usually last for few minutes or sometimes they last to continue for two to three hours. It is eminent that in case of cloudburst extending for long periods large magnitude of devastation occurs. It proves that this damage is worse than the combined effect of rainfall of the whole year. Relentless and continuous lesser intensity rainfall also activates landslides at numerous places. Thus the combine affect of continuous rainfall and the sporadic cloudbursts results to numerous and devastating landslides.

Another heartening reason behind slope instability is human interference. Removing of slope support for widening of roads also triggers landslide in areas where topographic slopes and dips of beds are consistent, with beds dipping at equal or lesser amounts than hill slopes. Overcapacity of slopes or removal of lateral support by human hindrance is one most important concern for slope failure in these areas. Soil cover in the area enhances plentiful vegetation but urbanisation and other human actions have distressed the natural processes exposing the soil to water action, which ultimately results in extensive surface erosion and slope instability. Improper drainage system in the area has added more problems in causing instability. Cultural practice like terrace cultivation for paddy in old landslide areas where the soils are rich in silt and clay, traps water for about 60 days during the planting season, whereby complete saturation and extreme pore pressure is generated leading to slope failure. Such terraces are familiar in patches along the highway leading to continuous subsidence and damage of the road particularly during monsoon.

8.2 CONCLUSIONS

Landslide investigations ought to promote disaster preparedness and to establish a network of efficient operation for all disaster related activities during pre-disaster period, at an actual disaster and afterwards. Therefore the current study made an effort to create a landslide record based on field studies using topographical maps and satellite records in a GIS background, as there is lack of information on landslides. The landslide hazard map produced can serve as a mechanism that can serve as an effective channel for proper planning, formulation of policy and decision making through data integration and modeling. The 3-D models can be suitably used to

Plate 8.1.f Local fault

Plate 8.2 Water draining in an unstable area

evaluate and view the rugged terrain and plan accordingly. Such data can be simulated for use elsewhere under similar condition. Geotechnical investigations have proved to be significant for the prediction of future landslides so investigations have been cautiously undertaken to help device fitting control and preventive measures.

Drainage system in the studied area is improper and very poorly constructed. This has led to surface run-off along the whole unstable area and also leading to huge percolation of water into the subsurface making the soil lose its shearing strength and causing failure. Therefore, drainage enhancement should include surface and subsurface clearance. To enhance surface drainage it has to take care of lined catch-water draw off above the crown of a slide, lined contour drains at different levels of the slide mass and lined cascading chutes to intercept and divert rainwater from the upslope so that water will not enter present and old landslide zones (Plate 8.2). Splashing of impermeable material like tar mulch or mortar at the crown and head regions can also be opted to shut any tension cracks and other permeable zones that provide avenues for excessive water infiltration.Such technique can help check infiltration and ease pore water pressure appreciably. Subsurface drainage development works can minimize and remove groundwater from within the landslide mass and it can lower the groundwater table. It can be of any type like the low or deep subsurface drainage control mechanism which again depends upon the nature of the slide. Some systems that can be interpolated are intercepting under drains, interceptor trench drains, horizontal gravity drains and drainage wells.

Though some fresh cut slopes along the roads actually remains stable, a number of places generate devastation as the debris from the slopes tears down the bitumen on the road. The techniques used for construction of road in this part of the region are very poor. Thus the technique and material used for road construction in high hazard zones should really improve. A wiser alternative in badly deformed areas would be realignment of roads, innovating as far as possible to reduce cost, improve speed of construction, and encourage utilization of slope waste to the amount viable.Other weak parts of the highway away from the study area should also be considered though mitigation plans in all the landslide prone area may not be achievable due to unaffordable expenses, engineering and economic feasibility and social acceptability. However improvement methods should be adopted to reduce cost.

Random cutting of slope for road construction and altering the nature of slope in bringing about development should be stopped. With urbanization and development, slope instability problem along NH 39 has been drastically disturbed by human activities in the form of unsystematic agricultural practices, construction of RCC buildings and other land use practices. Ultimately it has increased the load on hill slopes. People should be highlighted and made conscious of these specifics that such constructions make the slope more vulnerable and should be encouraged to use light construction materials. An example that can be cited in this circumstance is the Landslide Mitigation Programme of Japan (NAP, 1987) where the Japanese Government set up land use management controls for agricultural practice and building construction. Since it got implemented it helped a lot, as it noticeably reduced the loss of lives and property in the country. As pointed out, age old practise of jhum or shifting cultivation and terrace cultivation should be discouraged as it compounds the problem due to retention of water for longer period of time, increased degree of mass wasting, siltation, and other ecological imbalances. So, instead of these practices, an alternative is plantation of cash crops, etc. which can minimize the problem of slope failure to a great extent. Inspection of vehicles beyond the allotted weight and minimizing vibrations from vehicular movement can all contribute in some ways to stabilize the area.

Afforestation can be encouraged so that it will minimize excessive infiltration and surface runoff. To help control the slides planting of different species of grass such as Ginni Grass, Napier Grass, Java Grass, Lemon Grass, Palma Rosa Grass, Golda Grass, etc will ensure more stable slope. Planting fast growing, deep rooted trees such as eucalyptus, alder, cedar, willows like *Salix tetrasperma*, *Salix ichnostachya Lindl* and *Salix sitchensis* and fir like *Pseudo tsugamenziessii* in the lower reaches of slide zones also help in stabilizing the slope. However, planting of large and heavy trees on highly susceptible slopes should be avoided, as these plants may compound the problem as they grow larger and taller and infact unstabilize the slope because of its weight.

After thorough study, engineering mitigation procedures such as pilling, tie bars, soil nailing and designing special types of retaining walls or other slope stabilizing structures may be taken up to stabilize the slopes to some extent. Rock slope engineering therefore is necessary and important as slope forming materials are quite fragile and thick.

Precise and accurate weather forecasting of cumulative rainfall patterns can warn people of an approaching storm and prevent devastation to a considerable degree hence this information have become an important tool. Therefore, for better planning and proficient investigations it is necessary to install more rain gauges at various places to obtain more accurate and detailed data.

Bhandari (1984) has given importance to instrumentation and field monitoring of landslides and other mass movements as such gadgets in unstable, site specific, prone areas and habitated areas can help in untimely warning and evade from major disasters.

From geotechnical studies of soils along the hilly routes of NH 39 it has also been found that the soils contain clay sediments of organic matter mainly because of terrace cultivation, or it may be because of other anthropogenic activities. Studies have indicated that during the rainy season, natural water content is high, going beyond the plastic limit and possibly during certain seasons the water content exceeds the liquid limit. From index properties of these soils it is observed that when the natural water content is high, the liquidity, consistency indices approach the critical limit, implying the possibility of slope masses going into the liquid state, leading to slides and flows of the slope materials. Studies of the two slides have established that the soils are in a state of near failure. The soils are highly saturated though they have been collected during the lean period, indicating that during the monsoon period the saturation of the soil will be even higher making the soil even more unstable leading to slope failure. Consistency properties of the soil show near zero and negative values, which indicates near failure in the future. Hence, slopes cut greater than the internal friction angle will be unstable. That is to say that, landslides will be common if the slope cuts are more than 16° and 13° in these two particular studied areas. Probably this is the reason why slides are common during rainy season.

Forming active and proper Landslide Management and Regulatory Board by the Government to check and examine instability is thus recommended. Programs for educating people should be taken up to make them aware of proper land use practice on the slopes as well as construction designs for hill roads, buildings, etc. Governing establishments should check that no plans are cleared unless satisfactory provisions are made for fullest investigation and protective measures are guaranteed. Alcedo (1998) cited that well-implemented disaster mitigation programs will professionally contribute to reduce the physical, social, and economic vulnerability of disaster prone areas.

It can be seen that the Bureau of Indian Standards (BIS) and the Indian Roads Congress (IRC) have no proper specification and recommendation for construction of roads in hilly areas. Hence, further research in engineering and construction techniques for slope stability for hill roads will help improve safety measures and loss of lives.

From the LHZ map generated, the high hazard and very high hazard areas are clearly distinguished. Thus these areas must be considered in terms of probable risk to property and human lives. Disaster preparedness and remedial management programs in whatever achievable way for these areas must be worked out immediately. Thus it is necessary to have implementable plans in place and for which resources should be available.

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