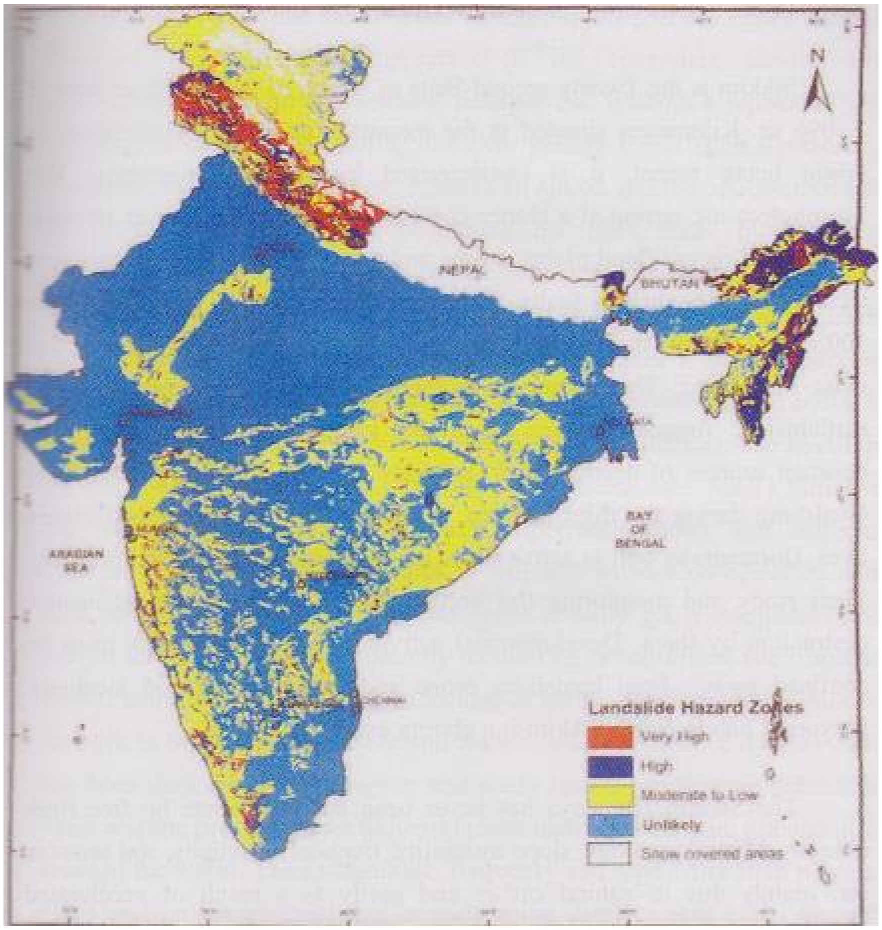
LANDSLIDES HAZARDS ZONATION MAP OF INDIA



LANDSLIDES IN SIKKIM

The common sight of relief, swathes of verdant forest, raging fast flowing rivers and rivulets, steep slope that are under failing and failed condition, high seismicity and so on characterize the mountain ecosystem of the Sikkim Himalaya. Considering the fragility, diversity and complexity of the existing geo-environmental setting and the ecosystem, manipulation of natural constant either by nature or man in an unsustainable manner can lead to irreparable short as well as long term negative side effects and devastation.

Sikkim is the Twenty second State Union of India with an area of 7,096 sq. Kilometers situated in the mountainous Eastern Himalayas. Its origin being recent, it is characterized by rugged topography. The Morph tectonic setting at a glance consists of, deep ravines, rivers terraces, ancient and recent flood plains, steeps and gently sloping hills various geotectonic feature such as faults, folds etc. The altitude of areas vary from 300 m.a.s.l to 8598 m.a.s.l The State of Sikkim is plagued by various type of mass movement. The triggering factors are invariably excessive water, earthquakes, and ruggedness etc. Landslides triggered by heavy rain been constant sources of destruction of property and loss of lives. Landslide at Gyalshing during the third and last week of August 2000 claimed eleven lives. Dormant as well as active slides are threat to human life and property. Their study and monitoring has become imperative to safeguard against destruction by them. Developmental activities to be sustainable must be confined away from landslides prone and landslide affected locations Meyong Chub in North Sikkim is a glaring example.

The Sikkim Himalaya has never been and will never be free from ubiquity of weak geology, slope instability, frequent seismicity, soil erosion etc. mainly due to natural causes and partly as a result of accelerated degradation. These adverse conditions in tandem can exacerbate the existing fragile, vulnerable and multi-functional mountain ecosystem. So far disaster caused by landslides, earthquake, flood etc. have not led to large scale human tragedy in Sikkim recent memory. However, there is ever increasing human demand of natural resources, especially land for urban development and mega dams in an apparently unsustainable manner, making some of the denizens to adapt and survive at dangerous margins. The emerging crisis can be minimized by indigenous knowledge based and modern technological interventions. To safeguard against accelerated degradation and improve the living standard of hill people, the Government (center and state) needs to address hill specific issues through systematic and affective integration of the ecosystem service and development, highland and lowland linkages etc. Without a replicable and hill specific development policy, the ever present threat form devastating landslides, earthquake, flood etc. remains an option and opportunities of the progeny in jeopardy. A beginning has been made by the state Government of Sikkim by asking the Department of Science & Technology (DST), Government of India to undertake systemic study of landslide problems in the State. The DST accordingly prepared a status report on landslide in Sikkim. Base on the report, the DST, Government of India, is considering establishment of a multi-disciplinary cell dedicated to landslide studies, not only in Sikkim but the entire Northeastern State. Such an initiative has become imperative because past experience shows that different agencies carry out landslide studies at will land and without coordination with each other. Results of such exercise never actually got disseminated and proved futile. Whereas the seismicity monitoring is concerned, site response studies using digital accelographs located at seven – station –strong motions network in Sikkim by year 2000 and twelve –station network by year 2006 has been done by IIT, Kharagpur and study results widely published. Mass wasting processes area universal phenomena in mountain, hill and hilly areas of the world. Their magnitude, frequency and type differ from place to place and on the material that is undergoing displacement either through chemical or mechanical means. In the Himalayas, mass wasting process is dominated by landslides. The magnitude, intensity and frequency of Himalayan landslides vary from East to West and from South to North. The variation is controlled, mainly by climate, neo-tectonism and seismicity. The eastern Himalaya including Sikkim is a hot-spot for natural hazards, particularly landslides and earthquakes. Landslides of all types and size occur in almost all types of rocks and quaternary formations of Sikkim. The Daling Group of rocks, especially, Goribathan Formation appears more prone to landslides then the inhomogeneous quaternary deposits and gneisses and schist of Higher Himalaya. The high landslide susceptibility of the Daling Group of rocks has been attributed to their severe shear distortion due to loading and unloading during or genesis, higher rate of weathering and mineral composition. A cursory survey of frequency of occurrence of landslides in Sikkim was done in 1991 and result clearly showed that the East and South District where Daling rocks dominate are affected by maximum number of landslides (Table no 13). Landslides are common phenomenon in a mountainous area having high relief. Landslides and other types of mass movements have always attracted the attention of human in the same way as other uncontrollable phenomenon of natural disaster like earthquakes, volcanoes and floods, which threaten the life and property of inhabitants. In some areas, the occurrence of landslides or other types of mass movements are less, but in a mountainous region with higher relief accompanied by tectonic activities as in Sikkim, various shapes or types of mass movements can take up disastrous turn at times. The mountain slope are governed by laws of gravity and with the forces of lubricant like water, the unstable slope-forming material shall continue to move downwards and cause economic loss in terms of life and property. Landslide with heavy rainfall causes flash floods in the valleys. Landslides or mass movement phenomena in a mountainous state like Sikkim lying over the young mountain chain can be attributed to the following causative factors solely or in combination with:

1. Geology of the area.
2. Geo-technical condition.
3. Rainfall.
4. Slope angle and slope formation materials.
5. Hydrological condition of the area.

Rainfall particularly in the Sikkim Himalaya is often punctuated by flashes of cloudburst. A cloudburst comes with the speed of thunder, lasts for a few minutes to as long as three hours at stretch of time, and usually leaves behind a trial of devastation worse than inflicted by the combined effect of rainfall in the same area, for the rest of the season. Rainfall record of the Teesta Valley for the period 1891-1965 speaks of rainfall intensities exceeding 250 mm in 24 hours, repeated more than 40 times! Taking the mean annual precipitation as 5000 mm for the Teesta Valley, the Event Coefficient (Ce =precipitation record of the event/mean annual precipitation) can be calculated. Thus, event coefficients (Ce) do range between 0.069 and 0.36, which are remarkably high values from any standards and are usually associated with landslides' on the lower side of the scale and landslide disasters on the higher side of the scale. Admittedly, conclusions derived from study of 'event coefficients' alone, without cognizance of rainfall records prior to the event and without knowledge of landslide history of the area may be deceptive. However, the fact remains that 'cloud bursts' of intensities exceeding 1000mm in 24 hours ($Ce>0.2$) trigger mass movements practically in any circumstances, and for $0.1<Ce<0.2$, probability of mass-movement is pretty high. For $Ce<0.1$, biunivocal (unequivocal) relationship between rain and slides does not seem to exist.

Landslide types and classification

Various scientific disciplines have been developed taxonomic classification system to describe natural phenomena or individuals, like for example, plants or animal. These systems are based on specific characteristics like shape of organs or nature of reproduction. Differently, in landslide classification, there are great difficulties due to the fact that phenomena are not perfectly repeatable; usually being characterized by different causes, movements and morphology, and involving genetically different material. For this reason, landslide classifications are based on different discriminating factor, sometimes very subjective.

In the following, factors are discussed by diving them into two groups:

(A) The first one is made up of the criteria utilized in the most widespread classification systems that can generally be easily determined.
(B) The second one is formed by those factors that have been utilized in some classifications and can be useful in description.

Types of movement

This is the most important criteria, even if uncertainties and difficulties can arise in the identification of movements, being the mechanisms of some landslides often particularly complex. The main movements are falls, slides and flows, but usually topples, lateral spreading and complex movements are added to these.

Material Involved

Rock, earth and debris are the terms generally used to distinguish the material involved in the landslide process. For example, the distinction between earth and debris id usually made by comparing the percentage of coarse grain size fraction. If the weight of the particles with a diameter greater than 2mm is less than 20%, the material will be defined as earth; in the opposite case, it is debris.

Activity

The classification of a landslide based on its activity is particularly relevant in the evaluation of future events. The recommendation of the WP/WLI (1993) defines the concept of activity with reference to the spatial and temporal conditions, defining the state, the distribution and the style. The first term describes the information regarding the time in which the movement took place, permitting information to be available on the future evolution, the second term describes, in a general way, where the landslide is moving and the third term indicates how it is moving.

Movement velocity

This factor has a great importance in the hazard evaluation. A velocity range is connected to the different types of landslides, on the basis of observation of case history or site observations.

The age of the movement

Landslide dating is an interesting topic in the evaluation of hazard. The knowledge of the Landslide frequency is a fundamental element for any kind of probabilistic evaluation. Furthermore, the evaluation of the age of the landslide permits to correlate the trigger to specific conditions as earthquakes or periods of intense rains. It should be noted that, it is possible that phenomena could be occurred in past geological times, under specific environmental conditions which no longer act as agents today. For example, in some Alpine areas landslides of the Pleistocene age are connected with particular tectonic, geomorphologic and climatic conditions.

Geological conditions

These represent a fundamental factor of the morphological evolution of a slope. Bedding altitude and the presence of discontinuous or faults control the slope morphogenesis.

Morphological Characteristics

As the landslide is a geological volume with a hidden side, morphological characteristics are extremely important in the reconstruction of the technical model.

Geographical location

These criterions describe, in a general way, the location of landslides in the physiographic context of the area. Some authors have therefore identified landslide according to their geographical position so that it is possible to describe “alpine landslides”, “landslides in plains”, “hilly landslides” or “cliff landslides”. As a consequence, specific morphological context are referred characterized by slope evolution processes.

Topographical criteria

With these criteria, landslides can be identified with a system similar to that of the denomination of formations. Consequently, it is possible to describe a landslide using the name of a site in particular, the name will be that of the locality where the landslide happened with a specific characteristic type.

Type of climate

These criteria give particular importance in the genesis of phenomena for which similar geological condition can, in different climatic conditions, lead to totally different morphological evolution. As a consequence, in the description of a landslide, it can be interesting to understand in what type of climate the event occurred.

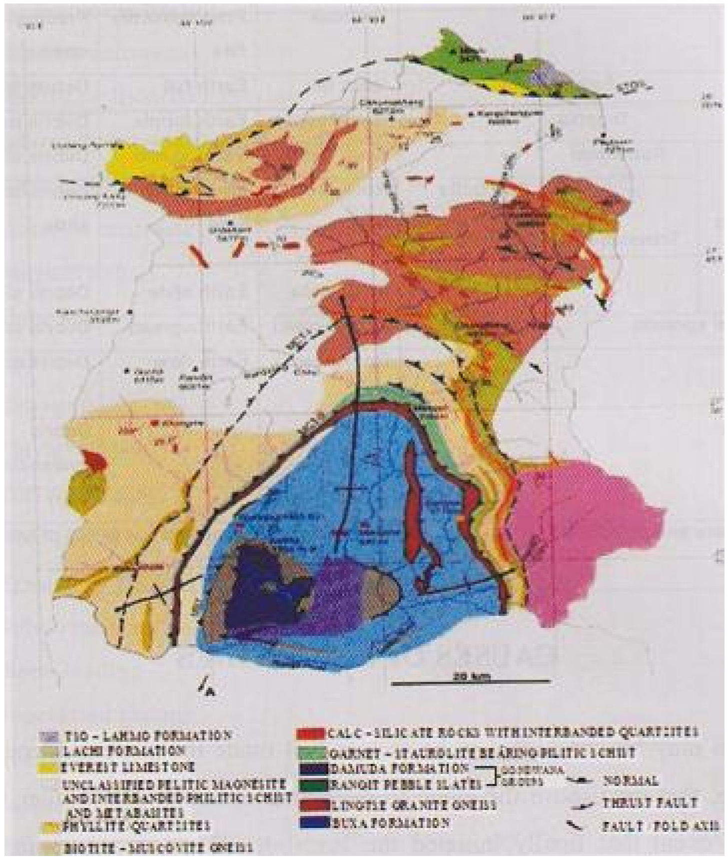
GEOLOGY AND TECTONICS

Millets (1875) & Bose (1891) were the first explorers who gave an account of geology and mineral resources of Sikkim Himalaya. Subsequent exploration by Auden (11935), Heim and Gansser5 (1939), Ray (1947), Gosh (1952), Raina and Srivastava (1980), Thakur (1986), Ravikant (1993), Neogietal (1989), Ray (2000) and others gave important and valuable contributions towards understanding of geology of Sikkim.

The current literature describe geology of Sikkim similar to that of the Eastern Himalayas where four, distinct geomorphology based transverse zone or tectonic stratigraphic domains, separated by major tectonic dislocation, are exposed in Sikkim. The Lesser, Higher and Tethys Himalaya of Sikkim are typically arranged in a domal shape or arch of thrust surface in the form of culmination across Teesta river, popularly known as Teesta culmination (Mcclay, 1992, Ray, 2000). The core of the Teesta culmination is occupied by Proterozoic Lesser and Higher Himalaya crystalline complex, the main central Thrust (MCT) separates the lesser and Higher Himalaya. Gondovana (carboniferous to permain) and Buxa Group of rocks are exposed in the Rangit window Zone, small window near Rorathang east Sikkim and as thrust / fault slices in South Sikkim. The Tethys Himalaya is represented by cambrain to Eocene fossilferous sediments of North Sikkim Tethyan Zone which tectonically overlie the Higher Crystalline Complex (see map below).

CAUSE OF MOVEMENTS

Terzagi describes causes as “internal” and “external” referring to modification in the conditions of the stability of the bodies. Whilst the internal modifications in the material itself which decreases its resistance to shear stress, the external causes generally induce an increase of sheer stress, so that block or bodies are no longer stable. It should be noted that the triggering causes induce the movement of the mass. Predisposition to movement due to control factors is determining in landslide evolution. Structural and geological factors, as already described, can determine the development of the movement, inducing the presence of mass in kinematic freedom.



Geology and Stratigraphy of Sikkim (from CCSTB,CISMHE)

TYPE AND CLASSIFICATION

In the following table shows a schematic landslide classification adopting the classification of Varnes 1978 and taking into account the modifications made by Cruden and Varnes, in 1996. Some integration has been made by using the definitions of Hutchinson (1988) and Hungretal 2001.

Types of movement			Type of material		
			Bedrock	Engineering soils	
				Predominantly Fine	Predominantly coarse
Falls			Rock fall	Earth fall	Debris fall
Topples			Rock topple	Earth topple	Debris topple
Slides	Rotational		Rock slump	Earth slump	Debris slump
	Translational	Few units	Earth block slide	Earth block side	Debris block slide
		Many units	Rock slide	Earth slide	Debris slide
Lateral spreads			Rock spread	Earth spread	Debris spread
Flows			Rock flow	Earth Flow	Debris flow
			Rock avalanche		Debris avalanche
			(Deep creep)	(Soil creep)	
Complex and compound			Combination in time and /or space of two or more Principal types of movement.		

CAUSE OF LANDSLIDES

Causes may be considered to be factors that made the slope vulnerable to failure, that predispose the slope to becoming unstable. The trigger is the single events that finally initiate the landslide. Thus, causes combine to make a slope vulnerable to failure, whilst the trigger finally initiates the movement. Landslide can have many causes, but can only have one trigger as shown in the next figure. Usually, it is relatively easy to determine the trigger after the landslide has occurred (although it is generally very difficult to determine the exact nature of landslide triggers ahead of a movement event).

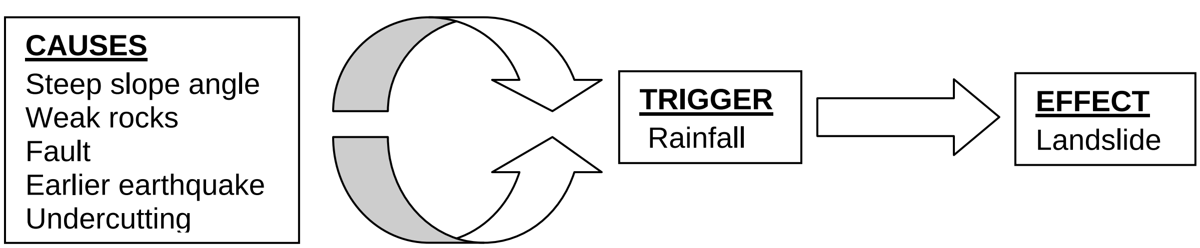
1. **Geological Factors**
    a. **Weak materials**
    b. **Sensitive materials**
    c. **Weathered materials**
    d. **Sheared materials**
    e. **Jointed or fissured materials**
    f. **Adversely oriented discontinuities**
    g. **Permeability contrasts**
    h. **Material contrasts**

2. **Morphological causes**
    a. **Slope angle**
    b. **Uplift**

    c. **Rebound**
    d. **Fluvial erosion**
    e. **Wave erosion**
    f. **Glacial erosion**
    g. **Erosion of lateral margins**
    h. **Subterranean erosion**
    i. **Slope loading**
    j. **Vegetation change**

3. **Physical causes**
    a. **Intense rainfall**
    b. **Rapid snow melt**
    c. **Prolonged precipitation**
    d. **Rapid drawdown**
    e. **Earthquake**
    f. **Volcanic eruption**
    g. **Thawing**
    h. **Freeze-thaw**
    i. **Shrink-swell**
    j. **Ground water changes**
    k. **Other mass movements**
4. **Human causes**
    a. **Excavation**
    b. **Loading**
    c. **Drawdown**
    d. **Land use change**
    e. **Water management**
    f. **Mining**
    g. **Quarrying**
    h. **Vibration**
    i. **Water leakage**

Example of landslide causation and triggering



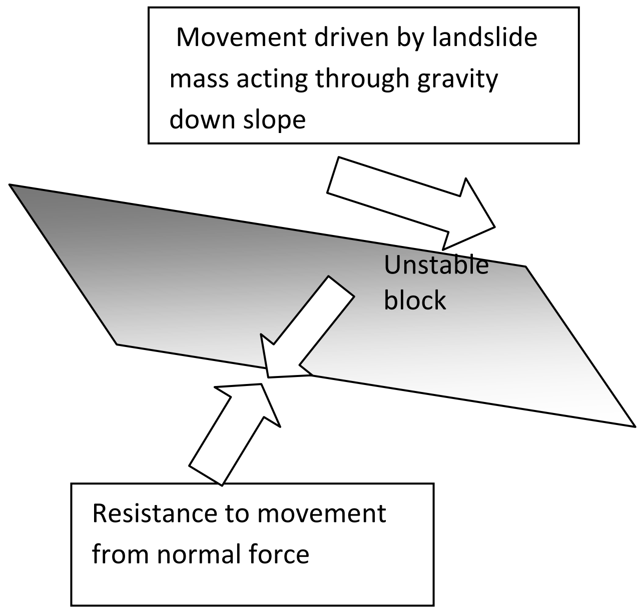
RAINFALL AS A TRIGGER

In the majority of cases, the main trigger of landslides is heavy or prolonged rainfall. Generally, this takes the form of either an exceptional short lived event, such as the passage of a tropical cyclone or even the rainfall associated with a particularly intense thunderstorm or of a long duration rainfall event with lower intensity, such as the cumulative effect of monsoon rainfall in South Asia. In the former case, it is usually necessary to have very high rainfall intensities, whereas in the latter the intensity of rainfall may be only moderate- it is he duration and existing pore water pressure conditions that are important. The importance of rainfall as a trigger for landslides cannot be under-estimated. Almost all the landslides in Sikkim occur after prolonged exposure to monsoon rains and occasionally during or just after cloudburst or precipitation intensity exceeding 135-145 mm in 24 hours.

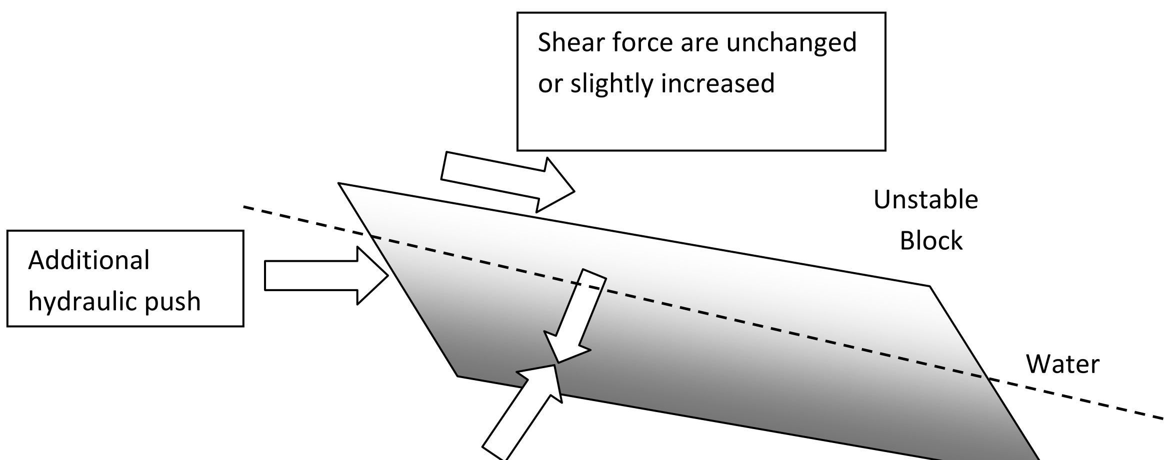
The red letter of October 1968 was considered the most disastrous in recent years of Sikkim history. On 5th September 1995 heavy rain triggered off a mud avalanche near Gangtok killing 32 people. Similarly, non-stop heavy rain since early June 1997 damaged 300 houses completely, 1000 houses partially and caused death of 51 people in east and North District of the state. Rain, therefore, has been one of the main triggers besides weak geology; steep slopes with thick overburden, frequent earthquake etc., and causing landslides (refer table no.37). So why does the rainfall trigger so many landslides? Principally, this is because the rainfall drives an increase in pore water pressure within the soil.

The figure A illustrates the forces acting on an unstable block on a slope. Movement is driven by sheer stress, which is generated by the mass of the block acting under gravity down the slope.

Resistance to movement is the result of the normal load. When the slope fills with water, the fluid pressure provides the block with buoyancy, reducing the resistance to movement. In addition, some cases fluid pressures can act down the slope as a result of groundwater flow to provide a hydraulic push to the landslide that further decreases the stability. Whilst the example given in figure A and B is clearly an artificial situation, the mechanics are essentially as per a real landslide.



A: Diagram illustrating the resistance to, and cause of, movement in a slope system consisting of an unstable block.



B: Diagram illustrating the resistance to, and causes of movement in a slope system consisting of an unstable block.

In some situations, the presence of high levels of fluid may destabilize the slope through other mechanism, such as:

- Fluidization of debris from earlier events to form debris flows.
- Loss of suction forces in silty materials, leading to generally shallow failures (this may be an important mechanism in residual soils in tropical areas following deforestation).
- Undercutting of the toe of the slope through river erosion.

Considerable efforts have been made to understand the triggers for land sliding in natural systems, with quite variable results. For example, geologist is Puerto Rico, Larsen and Simon found that storms with a total precipitation of 100-200 mm, about 14 mm of rain per hour for several hours, or 2-3 mm of rain per hour for about 100 hours can trigger landslides in that environment. Rafi Ahmad, working in Jamaica, found that for rainfall of short duration (about 1 hour) intensities of greater than 36 mm/h were required to trigger landslides. On the other hand, for long rainfall durations, low average intensities of about 3mm/h appeared to be sufficient to cause landslide as the storm duration approaches approximately 100 hours. Coro minas and Moya (1999) found that the following threshold exist for the upper basin of the Llobregat River, Eastern Pyrenees area. Without antecedent rainfall, high intensity and short duration rains triggered debris flows and shallow slides developed in colluviums and weathered rocks. A rainfall threshold of around 190 mm in 24 h initiated failures whereas more than 300 mm in 24 - 48 h were needed to cause widespread shallow landslide. With antecedent rain, moderate intensity precipitation of at least 40 mm in 24 h reactivated mudslide and both rational and translation slides affecting clayey and silty-clayey formations. In this case, several weeks and 200 mm of precipitation were needed to cause landslide reactivation. A similar approach is reported by Brand et al. (1988) for Hong Kong, who found that if the 24 hour antecedent rainfall exceeded 200 mm then the rainfall threshold for a large landslide event Was 70 mm hr -1. Finally, Caine (1980) established a worldwide threshold:

$I = 14.82\ D - 0.39$ where: I is the rainfall intensity (mm h-1), D is the duration of rainfall (h)

This threshold applies over time periods of 10 minutes to 10 days. It is possible to modify the formula to take into consideration areas with high mean annual precipitations by considering the proportion of mean annual precipitation represented by any individual event. Other techniques can be used to try to understand rainfall triggers, including:

- Actual rainfall techniques, in which measurement of rainfall are adjusted for potential evaporation, transpiration and then correlated with landslide movement events.
- Hydro geological balance approaches, in which pore water pressure response to rainfall is used to understand the conditions under which failures are initiated.
- Coupled rainfall – stability analysis methods, in which pore water pressure response models are coupled to slope stability models to try to understand the complexity of the system.
- Numerical slope modeling, in which finite element (or similar) models are used to try to understand the interaction of all relevant processes.

DIFFERENT MITIGATION MEASURES TAKEN FOR LANDSLIDES

Installation of anchors anchors and nails on unstable rocky hillside

Reinforcement measures generally consist of the introduction of metal elements whose purpose is to increase the shear strength of the rock and to reduce the stress release created, for example, following cutting. Reinforcement measures are made up of metal rock nails or anchors. Anchorage can be classified as active anchorage, in the case in which they are subjected to pre-tensioning, and passive anchorage.

Passive anchorage can be used both to nail single unstable blocks and to reinforce large portions of rock. They can also be used as the pre-reinforcement elements of a scrap to be re-profiled in order to limit hillside decompression associate with cutting. In an anchorage are defined: the header : the set of elements (anchorage plate, blocking device, etc.) part of the anchor, concreted and otherwise, placed under traction; can be constituted by a metal rod, a metal cable, a strand, etc; the length of the foundation: the deepest portion of the anchor, fixed to the rock with chemical bonds or mechanical device, which transfer the load to the rock itself, the free length: the non- concreted length. When the anchorage acts over a short length it is define as bolt. It is, therefore, a specific type of anchorage, not structurally connected to the free length, made up of an element resistant to traction, normally a steel bar of less than 12m, protected against corrosion by a concrete health. As far as the anchorage device to the ground is concerned, it can be chemical, or use mechanical expansion or concerting.

In the first case, some polyester resin cartridges are placed in the perforation to fill the ring space around the end part of the bolt. The main advantage of this type of anchorage lies in its simplicity and in the speed of installation. The main disadvantage is in its limited strength. In the second case, the anchorage is composed of steel wedges driven into the sides of the hole. The advantage of this type of anchorage lies in the speed of installation and in the fact that the tensioning can be achieve in the instant the anchorage is put to work. The main disadvantage with this type of anchorage is that it can only be used with hard rock. Moreover, the maximum traction force is limit.

In the third case, the anchorage is obtained by concreting the whole metal bar: this is the most- used method since the materials are cheap and installation is simple. Injected concrete the mixes can be used in many different rocks and ground; moreover, the concrete sheath protects the bar from corrosion. The concrete mixture is generally made up of water and cement in the ratio W/C = 0.40-.45, since in this way a sufficient fluid mixture is obtained to allow pumping into the hole, while at the same time, when set, providing high mechanical strength. As far as the working mechanical of a rock nail is concerned, the strains of the rock induce a stress state is the nail composed of shear and traction stress, due to the roughness of the joint, to their opening and to the direction of the nail, generally non-orthogonal to the joint itself. The execution phase of setting up the nail provides for:

- Formation of any header niche and perforation.
- Setting up of a reinforcement bar (e.g a 4-6 m long FeB44k bar).
- Concrete injection of the bar.

Sealing of the header or the top part of the hole. It is, anyway, suitable to close up and cement any cracks in the rock to prevent pressure caused by water during the freeze-thaw cycles from producing progressive breaking in the reinforcement system set up. To this purpose, a producer is provided.

1. Cleaning out and washing of the cracks.
2. Plastering of the crack.
3. Predisposition of the injection tubes at suitable inter-axes, parallel to the crack, through which the concrete mix is injected.
4. Sequential injection of the mixture from bottom to top and at low pressure (1-3 atm.) until refusal or until to flow back of the mixture is noted from the tubes placed higher up. The injection mixtures will have approximately the following composition.

Cement – 10 kg

Water -65 l

Fluidity and anti-shrinkage additive or bentonite – 1 to 5 kg

Spriz –Beton (shot crete)

As defined by the American Concrete Institute “Shot crete is mortar or concrete conveyed through a house and pneumatically projected at high velocity onto a surface. There are two distinct processes of shot crete application: dry process and wet process. Often the term gunite is used, which refers exclusively to the dry process.

Drainage

The presence of water within a rocky hillside is one of the major factors leading to instability. Knowledge of the water pressure and of the runoff mode is the basic for being able both to carry out credible stability analyses, and to plan measures aimed at improving hillside stability. Hoek and Bray (1981) provide a scheme of possible measures that can be actuated on a hillside to reduce not only the amount of water, which they believe in itself to be negligible as an instability factor, but above all the pressure brought to bear by the water. The proposed scheme was elaborated taking three principles into account.

- Preventing water entering the hillside through open or discontinuity traction cracks.
- Reducing water pressure in the vicinity of potential breakage surfaces through selective shallow and sub-shallow drainage
- Placing drainage in order to reduce water pressure in the immediate vicinity of the hillside.

  The measures that can be achieved to reduce the effects of water can be shallow or in depth. Shallow drainage work has the main function of intercepting surface runoff water and keeping it away from potentially unstable areas. In reality, on rocky hillsides, this type of measures although contributing to reducing the amount of infiltration, alone is sufficient to stabilize a hillside.

Deep Drainage

Deep drainage is the most effective type of slope. Sub-horizontal drainage is very effective in reducing pore- pressure along crack surface or potential breakage surfaces. In rocks the choice of drain spacing, slope, and length is subordinated to, apart from the hillside geometry, the structural formation of the mass features such as position, spacing and discontinuity opening persistence condition, apart from the mechanical characteristics of the rock, the water runoff mode inside the mass. Therefore, only by intercepting the mostly drained discontinuities can there be an efficient result. The sub horizontal drains are accompanied by surface collectors which gather the water and take it away through networks of small surface channels.

Vertical Drainage

Vertical drainage is generally associated with sunken pumps which have the task of draining the water and lowering the groundwater level. The use of continuous cycle pumps implies very high running costs conditioning the use of this technique for only limited periods. Drainage galleries are rather different in terms of efficiency. They are considered to be the most efficient drainage system for rocks even if they have the drawback of requiring high technological and financial investment.

In particular, used in rocks this technique can be highly efficient in lowering water pressure. Drainage galleries can be associated with a series of radial drains which augment their efficiency. The positioning of this type of work is certainly connected to the local morphological, geological and structural conditions.

Geometry modification

This type of measure is used in those cases in which, below the material to be removed, the rock face is sound and stable (for example unstable material at the top of the hillside, rock blocks thrusting the hillside profile, vegetation that can widen the rock joints, rock blocks isolated from the joints).

Detachments measures are carried out there are risk conditions due to infrastructures or the passage of people at the foot of the hillside. Generally this type of measure can solve the problem by eliminating the hazard. However, it should ensured that once the measure is carried out, the problem does not re-emerge in the short term. In fact, where there are very cracked rocks, the shallower rock portions can undergo mechanical incoherence, sometimes encouraged by extreme of climate, causing the isolation of unstable blocks. The measure can be affected in various ways, which range from demolition with pick axes to the use of explosives. In the case of high and/or not easy accessible faces, it is necessary to turn to specialists who work acrobatically. When explosives and used, sometimes controlled demolition is needed, with the aim of minimizing or nullifying the undesired effects resulting from the explosion of the charges, safeguarding the integrity of the surrounding rock.

Controlled demolition is based on the drilling of holes placed at a short distance from each other and parallel to the scrap to be demolished. The diameter of the holes generally varies from 40 to 80 mm; the spacing of the holes is generally about 10 to 12 times the diameter. The charge fuse times are established so that those at the outer edges explode first and the more internal ones successively, so that the area of the operation is delimited.

Protection measures

The protection of natural and quarry faces can have two different aims:

1. Protecting the rock from alterations and
2. Protecting the infrastructure and towns from rock falls.

It is therefore, necessary to identify above all the cause of the alteration or the possibility of rock fall. Successively, the area of operations needs to be delimited the most suitable procedure to solve the problem and finally to control the effectiveness of the measure itself over a period of time.

The most –used passive protection measures are:

1. Boulder –gathering trenches at the foot of the hillside,
2. Metal containment nets, and
3. Boulder barriers.

As far as the boulder barriers are connected, they are generally composed of suitably rigid metal nets. Moreover, lately, various structural types have been put on the mark for which the manufactures specify the kinetic energy of absorption. One of the structural control methods for boulder containment nets starts from the concept of projectile collision, on the basis of which the maximum applied force and the corresponding resultant buckling are expressed, by means of a static analysis, leading to the quantification of the forces divided up among the various structural elements.

Another type of boulder containment barrier is the earth embankment, possibly reinforced with geo-synthetics (reinforced ground). The advantage of this type of work, compared to nets, is easier maintenance and lower environmental impact minor the absorption of kinetic energy is generally greater than that of metal nets.

GIS mapping of landslide vulnerable areas of South District (Study showing human vulnerability particularly due to landslides in South Sikkim.)

INTRODUCTION

Landslide is defined as a large mass of dirt and rock down a mountain or cliff. Landslide is the exterior and downward movement of the natural rocks, every sort of soli and artificial filling in other words the movement of the masses on the slope slides. Landslides are examples of geographical events. Naturally occurred landslides may cause loss of lives and property and also communication and transportation interruptions. Therefore; stages of landslide development and causes should be researched. In this study, the existing landslides in South Sikkim are examined. There are many active and potential landslide in this region. Morphology, geology, land cover, slope, elevation of then region are some of the triggers of landslide. The main aim of the study is; to produce a landslide risk/vulnerability come out with some practical and South District specific suggestion for control of landslides.

STUDY AREA: SOUTH SIKKIM

The South District of Sikkim has its headquarter at Namchi and its bound by Tista river in the East, Rangit river in the west and South Dzongu area of north district in the North. The District of South Sikkim has a total population of 1, 31, 525 persons (2001 census). Namchi is becoming a fast growing tourist destination basically due to its Natural beauty.

STATE PRIMARY CENSUS ABSTRACT OF TOTAL POPULATION -2001

SIKKIM (Table no 38)

Item	Sex	Total	Rural	Urban
1. Area in Sq. Kms		7.096.00	N.A	N.A
2. Total households		114,223	101,225	12,998
3 Total population (including institutional and houseless population)	P	540,851	480,981	59,870
	M	288,484	255,774	32,710
	F	252,365	225,207	27,160

Source: Primary Census Abstract

GENARAL GEOLOGY AND STRUCTURE

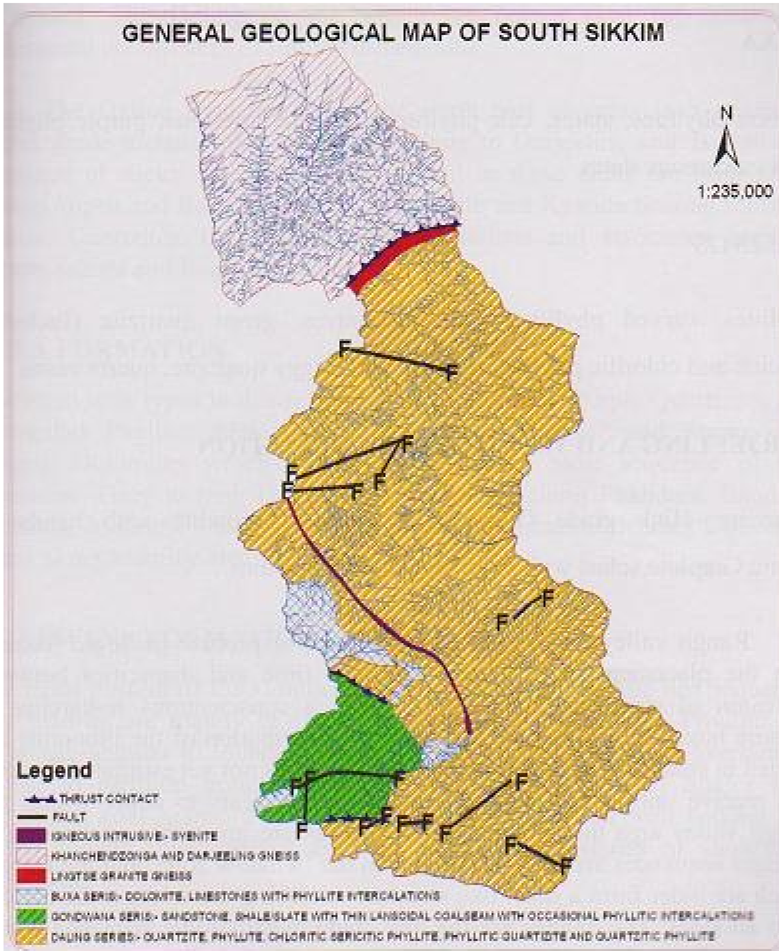
The area under investigation covers South District of Sikkim; Parts of Sikkim has been mapped geologically by a number of researchers from time to time. At each stage of mapping, additional details were added. In Sikkim Himalaya trouble begins when the question of stratigraphy comes up. Each researchers, over a period of time brings out their own stratigraphic classifications. They are yet to arrive at a commonly agreeable consensus because of lack of well documented markers such as fossils, horizons or features characteristic of these areas generally tolerated stratigraphic succession for **'Rangit Window Zone'** is as under:-

SOUTH SIKKIM TOTAL POPULATION -2001

(Table no 39)

Item	Sex	Total	Rural	Urban
1. Area in Sq. Kms		750	N.A	N.A
2. Total Households		25,477	24,726	751
3. Total population (including institutional and houseless population)	P	131,525	127,579	3,946
	M	68,241	66,096	2,145
	F	63,284	61,483	1,801
		Namchi		
Item	Sex	Total	Rural	Urban
1. Area in Sq Kms	*	*	*	*
2. Total Households		17,081	16,330	751
3. Total population (including institutional and houseless population)	P	87,350	83,404	3,946
	M	45,079	42,934	2,145
	F	42,271	40,070	1,801
		Ravang		
Item	Sex	Total	Rural	Urban
1. Area in Sq Kms		*	*	*
2. Total Households		8,396	8,396	*
3. Total population (including institutional and houseless population)	P	44,175	44,175	*
	M	23,162	23,162	*
	F	21,013	21,013	*

Source: primary Census Abstract : Census of India 2001, GOI



GONDWANA

Pebble slate, slates carbonaceous shale coal, sandstone and shale.

BUXA

Carbon phyllites, slates, calc-phyllite, dolomite/limestone, purple phyllite, dark calcareous slates.

DALINGS

Phyllites, varved phyllites, basic instrusives, green quartzite (fuchsite) sericitic and chloritic phyllites, massive and flaggy quartzite, quartz veins.

DARJEELING AND TSUNGTHANG FORMATION

Quartzite, High grade Gneiss, Granulite with bands of botite/Graphite schist with pegmatite and aplite veins.

Rangit vally ha seen as a place of profuse geologic features here the placement of lithounits in space, time and disparities between profusion of structural elements can lead a conscientious researcher to treasure house of new knowledge since the distribution of the lithounits are limited in space and mineral resources potentialities not yet estimated the area will receive only a cursory look each time for years to come within the Rangit valley area the stratigraphic sequences are always exposed in the 'window zone' and the Daling which are older form a sheet like structure enclosing the younger formations from all sides. The dalings are the low grade metamorphic sequence where the prominent lithounits are chorite, sericitics phyllites and massive quartzite. Flaggy type of quartzite within the darling are seen only near the contact zones invariably has been noted within the Daling of Rangit area quite regularly their placement within the sequences in space and time is not yet interoperated the quartz in intrusive, rampant in dalings seem to receive much attention from different geologists working in these areas. Their distribution and age in relation to the daling has been stipulated these intrusives are profuse throughout but as the dalings approach contact between the Daling and Darjeeling, their number decrease appreciably these intrusives are much latter then the dalings. In most cases they are the suited for the base metal occurrences though they are profuse their distribution in space is limited. The Daling on the whole are barren save for occasional basemental occurrences of limited dimensions.

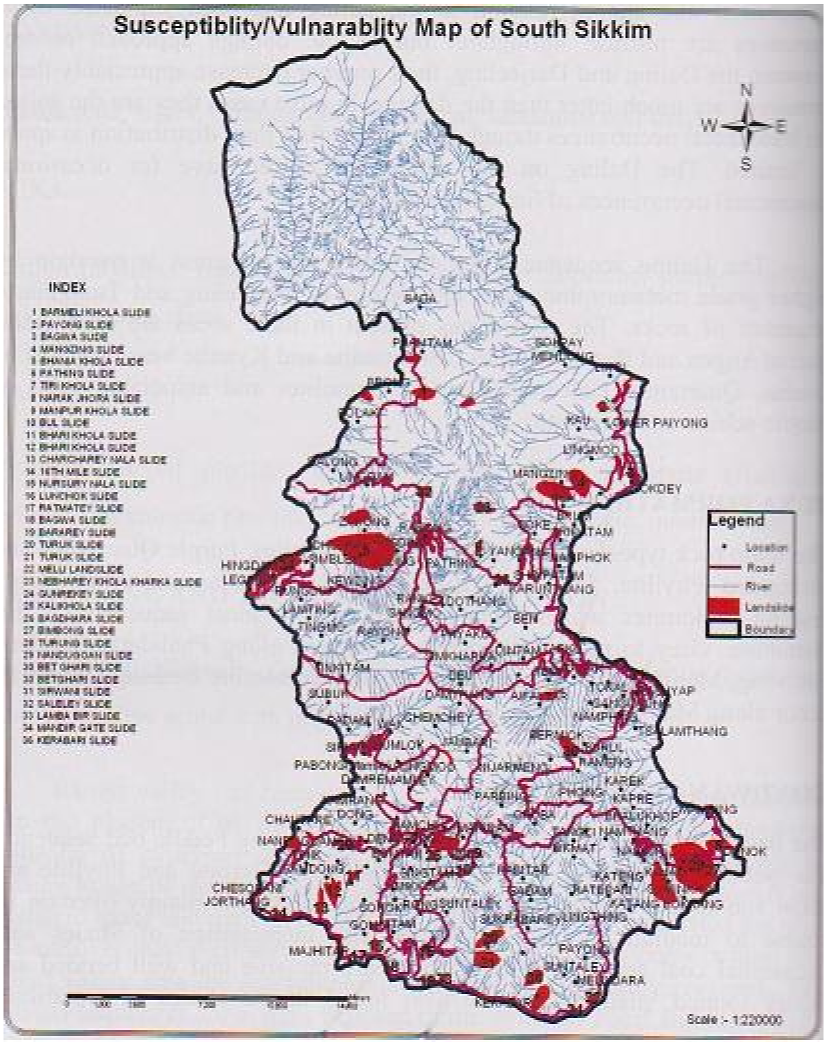
The Daling sequence along the north part of areas is overlain by higher grade metamorphic rocks that belong to Darjeeling and Tsungthang sequence of rocks. The rock types present in these areas are high grade gneiss(Augen and Banded Gneiss), Sillimanite and Kyanite bearing schist or Gneiss, Quartzites, Calcerous Gneiss, Granulities and associated band of Biotite schists and Pegmatite veins.

BUXA FORMATION

The main rock types of this formation are Dolomites, Purple Quartzite and veriegated Phyllites, Pink and Buff colored Dolomites and Stromatolite bearing Dolomites which belong to the upper most sequence of this formation. Grey and pink Dolomites are exposed alone Phalidara, Bagbara, Salibong, Mamley, Pabong and Wok areas. St romatalite Bearing Dolomites occur along Mamley areas.

GONDWANA FORMATION

The basal portion of the Gondwana is represented by Peddle bed sequence. The pebbles are mainly of Quartzite, Dolomite, Granite and Phyllites show sub-angular to rounded shape. The pebble-bed is mainly overlain by course to medium grained Sandstone with intercalation of Shales with occasional coal seams. The Sandstones are massive and well bedded and highly jointed, plant fossils are also found in the shales of Gondwana sequence.



NARAK- JHORA- SLIDE

Located along Rangpo-Namthang- Namchi roads 4kms (approx) from Rangpo towards Turung. (See pic. No 19)

Location – 27^{o} 9.767’ North latitude

88.31^{o}103’ East longitude

Length = 300mts Breath = 150mts.

Description

Area was inhabited by people with cluster of the east facing slope. The extreme weathering event of October 1968 caused massive slides in the area. Geologically the area consists of monotonous meta-sedimentary sequence equivalent to the Dalings (Pre-cambrain). Well bedded Phyllites / quartzite followed by chlorite- sericite-phyllite with strike N 30^o E to N 40^o E. The rock sequences dip almost along the slope.

Contributing Factors

Bed rocks structure and Inclination of slope

Reduction of sheer strength of rocks and soil

Extreme Precipitation event, occasionally concurrent with earthquakes

Destruction of Natural vegetation

Toe- cutting by high velocity streams

Other Human induced factors

TURUNG-BIMBONG SLIDE

Located around Turung and Bimbong village on valley side of Rangpo- Namthang road. (See Pic.No 20,21,22)

Location- 27^o 0.5258' North latitude

88^o 25.886' East longitude

Description

Village of Turung is located on the east facing slope that has been undergoing slope instability for ages and still plague by slides beneath the unstable slope forming material is repetitive sequence of quartz – chlorite/sericite phyllite, quartzite, ortho – quartzite with greywacke intercalations within Turung slide surface and sub- surface water movement also plays major role for Triggering the landslide. The other slide named as'Bimbong slide' at Bimbong village along the periphery of Turung area is characterized by the downward movement of thick soil overburden over the rock sequences as mentioned above. Turung and Bimbong slide together constitute one of the biggest active slides in Sikkim.

Localized failures are noticed along catchment area of Seti Khola towards east of Pamphok village.

KERABARI SLIDE

Located along Maniram – Sumbuk – Melli road Section at an altitude of 2073 ft (approx) and between

Location- 27^o 05.258' North latitude

88^{o}25.886' East longitude

Length = 100mts Breath= 40mts.

Description

As a result of weak geological formation, Surface and sub surface water pressures, adverse slope condition etc the slide is active at Present, the peripheral area of the main slide consisting debris with boulders of various dimension with immature soil is found creeping.

Another section in this region which can be categorized as unstable or slide occurring zone fall along Ratmatey, Turuk, Rong, Singtham, Bul, Salibong, Bomter, Kopche and Mikhoa. In case of Bomtar, Kopche and Mikhola areas, the geological/geotechnical set up holds good but with the road development activity with in discriminate cutting of the steep slope under PMGSY scheme various location has started failing which may later develop into major slides. In other areas failures are less common but are noticed along nala abutments due to scouring activities by the water run-off.

LUNGCHOK SLIDE

Location- Along Manipur- Sumbuk road

27^{o}06.636' North latitude

88^{o}21.905' East longitude

Length = 100mts Breath = 50mts (approx)

Description

Rotational type debris slide down a gentle slope failure is mainly due to pressure of thick unstable overburden which is further unstabilized by surface and subsurface water flow, construction of PMGSY road over the unstable spot, random disposal of the road construction waste, lack of scientific and technical input in the road construction activity etc.

TURUK SLIDE

Located at Turuk Village along tributary nala joining Manpur Khola from the eastern slope.(see pic no.23)

Location – 27^{o}, 6.5' North latitude

88^{o} 24'East longitude

Length= 100mts Breath= 800mts (approx)

Description

Slide along the slope to the west of Turuk village. The area comprises of sheared rock/soil mix sequence. The sheared rock consisting mainly of Sericite Phyllites is found overlain by red soil which failed over the steep slope under the triggering action of nala water. The scouring action of the nala has made adverse impact over the slippery Sericitic – phyllite rock sequence and the red soil overburden mass. The slide becomes active during rainy season when surface or subsurface water activity is maximum.

BUL SLIDE

` location- located to the south west of Bul village along Nala catchment

Between

$27^{o}08, 697'$ North latitude

$88^{o}23, 09'$ East longitude

Description

It is a small slide at an altitude of 2500ft amsl and situated Southwest of Bul Village. The failure occurred on the soil cover over the rock bed due to seasonal surface water run-off along the nala and scouring nala sides. The area consists of weak geological sequence comprising sheared Quartzite & Sericitic Phyllites rock sequence overlain by transported soil cover.

MANPUR KHOLA SLIDE

Location – located along the tributory nala that join Manpur Khola North East of Bul and above Salibong- Namchi road section at an altitude of around 4300ft- (approx) amsl.

Length = 100mts Breath = 20mts (approx).

Description

Fresh slide along the thrust/ sheared zone between the Dalings and Gondwana. The material that has undergone failing consists of sheared rocks belonging to above two formations. Occurrence of coal seam in the area with spring water sources has added stress to the slope material and caused the failure. Similar failings are found at Bomtar village and Kali Khola banks. Cases of subsidence or surface failure are common in the specified locations due to existence of sheared coal pockets and presence of surface & sub- surface water action in the area.

Other areas plagued by landslides in parts of south Sikkim are around Kamrang, Mamley, Jaubari, Kholaghari, Pabong, Wak, Tinkitam, Ralong, Polot, Borung and Sada – Phamtam areas.

The geological sequence in these areas comprise of the rocks belonging to Daling, Buxa and Gondwana sequences as a part Rangit valley window zone. Kamrang and Chamgaon areas near Namchi are represented in the area by phyllites and Quartzite rock sequences. Areas of Mamley, Pabong and Kholaghari comprise with the rocks of Buxa series represented in the area by Dolomites with signs of current bedding and presence of earliest plant fossil of Cambrian age-the Stromatolites. The Buxa sequence rocks in these areas are underlain by the rocks of Gondwana series represented by Shale/Phyllites, Sandstones with occasional coal seams which are exposed in areas of Pakjor, Lower Kamrang & Lower Mamley. Cases of Subsidences, Soil overburden creepare common in these areas because of abundance of water. Jarong, Daling, Barfung Hingdam, Kewzing, Ralong, Polot, Borong, and sada- Phamtam areas comprise of rock sequences belonging to daling series. The rocks are phyllites (ranging from Choritic, Sercitic Phyllites to gritty phyllite), quartzite and higher grademetamorphic rocks comprising of gneisses and schists. The areas of Upper Phamtham and Sada village comprise of high grade metamorphites with presence of high grade Gneisses, Calc – Granulites, Schist and occasional Tourmaline bearing Pegmatites. Kholaghari area experienced a massive flash flood in September 2003 and four people lost their lives due to unusual, unexpected cloudburst. Kholaghari Bridge was wased away. The areas close to Namchi are generally dry and a result destructive landslides are few and far in between.

The landslides in the district of south Sikkim as mapped by the team are as below:-

TIRI KHOLA SLIDE

Location- along Namchi- Kamrang-Mamley road at Tiri Khola between-:

27^{o} 11 'North latitude

88^{o} 22 'East longitude

Description

A small patch of mud flow owing to movement of sheared coal seam with overlying soil cover under the influence of surface and sub-surface water and scouring of khola banks by Titi khola water. The process becomes active during monsoon rains and disrupts vehicular movements.(see Pic. No27)

Failure along banks of Torikhola and flooding at Kholaghari area

Tori khola water flowing down from Jaubari area at the upper reaches is overcharged during monsoon and causes flash floods and scoures the banks of kholaghari khola during rainy seasons. Flashflood during the cloudburst of 2001caused loss of human life and damage of properties.

BANIYA KHOLA SLIDE

Location – Along tributary & Main nala of Baniya Khola at Burfong-:

27^{o} 17.5, North latitude

88^{o}21' East longitude

Length = 300mts Breath = 150 mts (approx).

Description

Slide along main and tributary Nala of Bainya Khola initiated and triggered by the surface water and Nala water movement over the weak geological condition of the area. Sericitic phyllites sweelwhen saturated with water and tend to get loose and degraded and the water acting as trigger mobilizes the movement of the degraded rock sequence along with soil cover. Areas around Barfung Doling have come under the impact of this slide. Large part of the land is lost. Becomes active during rainy reason.

GUNDRUKEY NALA SLIDE

Location: - located along Legship- Tashiding road near Rangit River

Between

27^{o} 17' North latitude

88^{o}17' East longitude

Length = 50mts Breath = 100mts (actual but impact area is large)

Description

A landslide located on steep slope with weak geological sequence and triggered by seasonal water run-off. The slide disrupts the Vehicular traffic during monsoon leading to Tashiding & Yuksom town. The weak geological sequence comprising of sheared Sericitic phyllites with medium thick soil overburden fails under the impact of excessive subsurface & surface water. The rock- soil mix debris is deposited over the road during the times of flash flood.

Other areas of landslide in parts of South Sikkim fall along Ravangla, Pathing, Yangyang, Niya-Brum, Manzing, Lingmo and Lingi-Payong areas. These area are again prone to landslide basically due to adverse geology, steep slope, presence of water etc. further, slope condition along with human induced factors contributes for destabilization of the slope in these areas. The identified and important cases of slope failure in the area are as described below:-

PATHING SLIDE

Located along up-slope (hillside) of Ravangla – Yangyang road near Rangpo Khola at Pathing village

27^{o} 18.5' North latitude

88^{o}23' East longitude

Description

Failure of overburden on steep slope comprising of conglomeratic rock soil mixture, failure occurred at a steep slope above (up slope)road section due to mobilization of the rock-soil cover by surface water run-off during times of sudden cloud bursts at the upper reaches.

BAGDHARA SLIDE

Located along Ravangla- Yangthang road above Satam village at an altitude of 4720ft (approx).

27^{o} 16.920' North latitude

88^{o}24.878' East longitude

Length = 150mts Breath = 30mts

Description

The destructive slope failure at Baghdhara above Satam is not a true slide. It is a typical debris avalanche. The competent rocks mainly of quartzites of the area are highly and subjected to shearing due to local active faults. The sheared rock fragments and debris overburden on steep slopes occasionally fail at times of high intensity rain. During June - July 2007, debris avalanche from Baghdhara buried several houses, paddy fields etc at Satam village (Picture no 28,29,30). The location is likely to face such events in future also.

NEBHAREY KHOLA KHARKA SLIDE

Located above Rangang village near Yangyang at Nebharey-Khola Kharka at the head water of a tributary Nala of Brum Khola and is at 1520mts amsl (approx) & between (See Pic. No 31, 32 & 45)

27^{o} 18.425' North latitude

88^{o}24.921' East longitude

Description

The spot characterized by fragile geological set up consisting of highly jointed Quartzites and phyllite rocks inter binding sequence with medium thick soil overburden cover. The slope material consisting of rock fragment of all sizes with small amount of fine materials fails even without the effect of excessive ground and surface water. The debris avalanche appeared to have been started off by an earthquake initially. Frequent avalanche are continuing because of fragility of the slope forming materials on a steep slope. The instability in the area regards detailed study soon.

MANZING SLIDE

Located along Yangyong road at an altitude of 1520mts amsl and Covers almost the entire area of Manzing & Bande village. The slide killed 07 persons in 2005 during a sudden cloudburst. The location is about 22 kms from Ravangla at about one and half km from Niyadara.

27^{o} 19.720' North latitude

88^{o}27.764' East longitude

Description

Area is about one and half kms from Niyadara to Lingmoo along Yangyang- Lingmoo road and is under the impact of an active slope failure. Majors locations of failure are noticed along the

Nalas. Whole part of the area of Manging & Bande villages are under movement. Geologically, the area consist of quartzite and quartz cholorite/sericite phyllite interbanding rock sequences overlain by thick soil-rock mix cover. the The topograghy is of an old landslide zone and village stands over the earlier failed debris cover. The upper areas comprise of the rock exposure from where the overburden mass slided down and got deposited in the present village area. Scouring action by the existing tributary & main nala of Manzing Khola at time with heavy discharge of water during rainy season scoured its abutments and mobilized the whole overburden mass for movement towards down slope. As a result the whole village area is under the impact of creep movement, resulting houses in the vicinity. Cloudburst of 24th September 2005 created the debris avalanches and buried seven persons and 28 families were evacuated from the area. (See Pic. No 33, 34, 35, 36 & 37)

BAGWA SLIDE

Located along Lingmoo-Makha road section at lower Lingmoo village near Tista river just before reaching Makha Bazar.

N27^{o} 19.180' North latitude

E88^{o}26.764' East longitude

Description

Area comprise of rocks belonging to Daling sequence respesented by Quartzites and quart chlorite/sericite phyllites. The medium thick rock-soil overburden in the area failed due to excessive surface & Subsurface water run-off and is deposited along the river terrace of Tista River.

LINGI PAYONG AREAS SLIDES

A major old landslide exist at Paying village which is presently dormant and few cases of surface failure are noticed along tributary Nala of Ranghap khola at lower Lingi areas which become active during rainy seasons. The area comprises of medium grade rocks of Daling sequence with soil overburden, mobilizing agents like Nala water run-off scours khola abutments and after such failure the soil cover the area starts failing downslope.

The final segment for the description of landslides in parts of south Sikkim can be explained along Namphing-Tokal-Bermiok-Rambang-Dong-Chuba-Parbing-Lingding-Phong village which is connected through a road section connecting Sirwani to Phong through Bermiok-Tokal village. The major surface failure activated in these area are as below:-

SIRWANI SLIDE

Located just ahed of sirwani Bridge towards papung khola Singtam -Sirwani-Papung road; (see pic No38 & 39)

270 14' North Altitude

880 28.5' East Longitude

Description

The slide is a case of soil-debris failure over an area with weak geological condition triggered by scoring by wayward nala water and abundance of underground water movement. The crown portion of the failing area is located along Sirwani-Papung- Bermeak road.The wayward Nala water and loose soil and debris as the slope forming material combine contributed to the failure .The debris cover was brought down-slope during an extreme rainfall event in 2007 and has damage the roadside café by consisting ogf huge boulders, rock fragment and other fine materials.

BETGHARI SLIDE

Along -Bermeok -Perbing-phong road section near Raming village between

270 12.5' North Latitude

880 26'East Longitude

Description

Medium grade rock of dialing formation favourably oriented inside the slope with soil-overburden cover. The rock have failed along their joint planes with soil overburden by the action of Nala water (Khola).Frequent high intensity flash flood due tocloud - brust at upper reaches has made the area unstable .The slope movement process during rainy season in the area block the road for vechicular traffic for atleast three month a year .Near Rameng village few instance of surface failure are noticed along bank of tributary nalas of Kalej Khola along road section at around Parbing village.

MELLI-JORETHANG SALGHARI SECTION

One major stretch along south Sikkim covering the areas of lower reaches fall along the road section of 27km from melli to jorethang. Geologically, the area comprise of the rock belonging to low grade metaphorphic rock of Daling series along with rocks of Gondwana sequence expose at certain areas. The dalling sequence comprise of Quartzite-chlorite-sericite phyllite,phyllitic-quartizite or quartzitic-phyllite. The rocks belonging to Gondwana sequence which are expose along Rangit valley window zone are sandstone, shale with thin & lensoidal coal seams.chloride-sericite-phyllite is the majore unit of this section. The rocks containing sericite micar slippery and hence slips or splits along foliation plain in strike-wise direction which has cause failure on rock formed slope material. Small patches of rock failure are common occurrence along this unit. Occasional quartz veinsr are notice with presence of secondary mineralization(sulphide) in this unit. Quartzites are well exposed unit as interbanding sequence with the phyllites. Quartzites are present as massive,milky or grey unit to quartzitic - or phylitic quartzites.massive well jointed milky quartzites unit are present near Manpur khola. Other area comprise of phyllite and quartzite interbanding sequence along Melli - joethang road section. Areas along Nalas of Bhari &Charchary slows exposures of Gondwana sequence due to erosion along these Nalas. The area ahed on upper portion of sixteen - mile slide is also exposed with coal belonging to Gondwana series.

As the area fall along contact zone of tows straigraphic units with presence of sikkip thrust and crushed lensoidal deposit of coal, surface failure are common in this section. Red soil cover exist in the area around kitam Ratmatey and majitar which fail downslope under water saturated condition Nalas like Bhari khola has scoured its abutments and black coloured water is seen flowing due to presence ofpuiverized coal sediments. Manpur Khola, Rabi khola etc. also scour its bank and surface failure in areas having sericitic phyltics dipping along slope direction is common. From Melli to Jorthang, major slope failure locations are as follows.

MELLI - ROLU KHOLA SECTION

Melli slide:- case of surface failure near Melli.

Location : Near melli Bazar towarda jorethang

2705 North latiotude

88027 ½ East Longitude

Length = 50mts Breath = 75mts

DESCRIPTION

The area comprise of quartz chlorite -quartz sericite phyllite and quartzite interbanding sequences . The rock are subjected to folding, faulting etc and most of the rock slopes are overlain by varying thickness of soil or debris overburden. Melli slide is a complex slide triggered by weak geology, steep slope, depleting vegetation, active ground water regime, toe erosion by Teesta etc. The area is likely to be a perennial source of slope instability.

MANDIR GATE POINT

Location between

27.06 North Latitude

88 025 ½ East Longitude

Description

Between Melli-Jorethang road for 100 mts (approx) and extending towards karabari slide in the North, toe cutting action by Rangit River has initiated the slide. The other component for mobilization is the seasonal water run-off. The weak geological formation comprising quartz chlorite/sericite-phyllite with quartides with foliation planes down the slope with thick soil overburden cover is the cause for instability. The road section comprise of highly jointed stated rock sequences with exposures in areas around Hui Khola and Champa Jhora. Wedge failures of rocks are common in these areas. The area between Champa Jhora and Mayalu Jhora has points of active instability. The overburden soil cover is under the impact of toe cutting action by Rangit River. The area ahead upto Rolu Khola is comparatively stable with few instances of wedge failures.

ROLU KHOLA MAJHITAR RIDGE POINT

Along the road section from Rolu Khola upto Majitar, instance of slope failure are encountered. This area comprise of rock of daling series and the rock present here are quartz- chlorite - sericite phyllite and quartzites.The quartzites range from pure milky quartzite to grey quartzites. The areas with seruicite - phyllite rock exposure facing towards slope are weak and fail under the impact of mobilizing agents like surface run - off, weight of overburden cover and by toe cutting action of Rangit River.

LAMBA VIR SLIDE

Located ahed of Rolu khola forwards manpur Glass Factory

27061/2'North Latitude

880221/2 East Longitude

DESCRIPTION

This landslide extends for nearly 100 m along the road section. The area comprise of quartz - chlorite/ Sericite phyllite and quartzites interbands. The slope of high degree and the fractured rocks slide down as avalanche as a result of wedge failure. The overburden soil cover also fails down - slope as trigged by surface run - of during monsoon period.

BARAREY SLIDE

Located approximately 75mts ahead of Lamba Vir slide towards Manpur. This area comprises of quartz - chlorite/sericite phyllite and quartzites rocks with thin to medium thick soil cover. This area has lot of surface and surface water activity. The weathered and water saturated quartz - chlorite/ sericite phyllite and quartzites rocks and has moved down slope as creep movement. This slide extends 150mts along slope and has extension towards lower Sumbuk Village in upper part.

BAGWA SLIDE

Location between:

2705.75'north Latitude

88021 East Longitudes

Length =150mts Breath = 75mts (approx)

DESCRIPTION

Landslide at Bagwa area is characterized by thick rock - soil mix that sloly creeps down slope. The contributing factors are toe - cutting action of Rangit River at the base and the heavy water movement along the head area. Hence, with toe -cutting action at the base of the slope and heavy seepages around the body of the slide, the slope material is moving downwards. The rock exposures in the adjacent areas dip north to Northwesterly and the slope faces south - westerly.

RATMATEY SLIDE

Located at ratmatey area near Majitar

27o5' North Latitude

88o20' East Longitude

Description

Located at about ½ km ahead of majhitar ridge point towards melli along jorethang-melli road section, area comprises of thick red soil overburden over quartzite / phyllite interbanding sequence. In this case, the failure of the over burden red soil cover is due to faulty road cutting, sensitivity of the slope farming material, surface,suf-surface & atmospheric water regimes and steep slope condition in the area.

SURFACE FAILURE PROBLEM MAJHITAR TO CHARCHAREY AREA

The area between majhitar to jorethang comprises of the rocks belonging to Daling series overlain by the rocks of Gondwana series. The rock of Daling series comprises of quartz-shlorite/sericite phyllite and quartzite's and highly jointed Quartzite's. These rocks are well expose along the road section. But from charcharey area onwards, boulders of sandstone and crushed cold /shale sediments are seen lying along road. failures of loose unconsolidated mass are noticed towards east of bhari khola. This is due to high surface and sub-surface water regime in the area with week geological condition. Failure are noticed at charcharey area where loose cold / shale bodies are scoured by nalas and are deposit along its bank and roads section.the stresses develop by the overburdens Gondwana rock-cover add for failure in the area.

16th MILE SLIDE

Located at half kilometer (approx) from jorethang towards melli between

27075' North Latitude

88017.3' East Longitude

Length = 150mts Breath =75mts (approx)

DESCRIPTION

Landslide is located near jorethang along road section. The area comprise of highly jointed quartzite with shared phyllite intercalation of daling sequence. These rocks are overlain by rocks of Godwana series represented by coal seam overlying the quartzite- phyllite intercalation. The slide used to block the road for vehicular traffic prior to 1995, but the mitigitave measures taken by the mines, minerals &Geology Department, of Sikkim has now controlled the failure.

Similar failure are common along jorethang - Namchi road section with coal seams, influence of water and depending on the scope angle and so on (see pic. No 74,75 & 76)

Limitation

There has never been a systematic study of landslide problems in Sikkim. Most of the existing literatures on landslide of Sikkim are written by some fancy expert expatriate on a whirlwind visit to the state. Since no to landslide are identical in any given area, it is not always easy to know the ground realities of mechanism that triggers off landslides. The state Department of mines, minerals & Geology, took up a number of landslide prone and affected areas for systematic study and so on. Some planer type slides controlled by joint, foliation and bedding planes were further subject to grouting and rock bolting, both tensioned and un - untensioned (see pics).Sikkim being a land locked state, disruption of road communication by landslide is an annual affair. For every linear kilometer of Sikkim's road, there are at least 10 minor to major slips.

CONCLUSION

Natural hazardous events such a earthquake, landslide, floods etc. in the Himalayas are a reality. Man and man- made structure stand no chance against the awesome power and fury of such events when they strike. Therefore, a mechanism is needed to safeguard against massive and unwarranted loss of life and property in the event of a calamity. In august 2004, the government of India came out with a detail status report on Disaster Management in India. The report specifies various programs and strategies of the national to tackle and mitigate all forms of destructive natural events. Translations of some of the recommendation have already begun in Sikkim. The government of Sikkim UNDP has undertaken various initiatives in this direction. The general public is sanitized through awareness training/talk show, mock drills, and banners and so on. The North eastern state including Sikkim being in high seismogenic domain, landslide and flood porn areas require special attention and constant vigilance. The ongoing research by established institution in various field of adverse events of graduation and monitoring by an apex authority for proper and effective coordination of long term research and dissemination of information to stake holders. The existing scenarios of haphazard and secretive study of natural events by all sorts of agencies need to be discouraged.

There are some regions for optimism. Solution to counter these trends exists and the knowledge and technology necessary to apply them are widely available. Disaster reduction is the sum of all the actions which can be undertaken to reduce the vulnerability of a society to natural hazards. The solution include proper land-use planning aided by vulnerability mapping to locate people in safe areas, the adaptation of proper building codes in support of disaster resilient engineering based on local hazard risk assessment, as well as ensuring the control ans enforcement of such plant and code based on economic or other incentive. Sound information and political commitment are the basic of successful disaster reduction measures. This is an ongoing process, which is not limited to singular disaster events. It motivates societies at risk to become engaged in conscious disaster management beyond traditional response to the impact of natural phenomena. Disaster reduction is multi-sect oral and interdisciplinary in nature and involves a wide variety of interrelated activities at the local, national, regional and international level.

RECOMMENDATION

The study of landslides by scholars in Sikkim have highlighted the uniqueness of the Sikkim Himalayas (eastern Himalayas include) in terms of geo-environmental setting, fragility, vertically, marginality, biotic and biotic environment, seismogenic character of the region and highly eventful nature of the prevailing hydrometer logical condition. The expert are of the opinion that the ubiquity of landslide in Sikkim is due to natural processes and/ or procreation is there to stay and therefore calls for creation of database on Landslide in Sikkim. They felt that such a database could serve as an important tool for decision making and developmental activities, especially in rural development projects. They, however, have not opined who should be the competent authority to generate such important data and that too consistently. Considering the recurring incidence of landslide and other mass movement year after year and their potential to damage man and material, establishment of a landslide monitoring, auditing and control cell in the state has become necessary. The cell should be manned by competent geologists, Junior level Civil Engineer and Surveyors. It should be made autonomous with technical, administrative, financial and legal power to function itself effectively for the benefit of State and the Nation.