1. INTRODUCTION

1.1. PROLOGUE

Landslides are one of the natural hazards that affect at least 15 per cent of the land area of our country - an area which exceeds 0.49 million sq. km. Landslides of different types are frequent in geodynamically active domains in the Himalayas and also in Indo-Burmese Range in the North-Eastern parts of the country as well as in the relatively stable domains of the Meghalaya Plateau, Western Ghats and Nilgiri Hills. In all, 22 states and parts of the Union Territory of Puducherry and Andaman and Nicobar Islands are affected by this natural hazard. The phenomenon of landslides is pronounced during the monsoon period. Landslides are the significant catastrophic process of nature and involve modification of surface morphology (Gupta et al., 1990). These are the results of complex processes controlled by factors like lithology, geological structure, geomorphological character, land use, groundwater, climate and seismic activity (Ferentino and Sakellaiou, 2001, 2003). These are serious threat to the human life and inflict great damage on farmland, forestland, communication network, building and other engineering structures resulting into serious economic problems. For example the maintenance expenditure of roads due to landslides in the Himalayan region is estimated to be Rs. 100 crore every year. Hence, landslides and other slope movements, like other natural disasters, viz., earthquakes, volcanoes and floods, have also attracted the attention of man in terms of their potential to cause devastating affect to mankind and the surrounding environment.

Mizoram is a rugged terrain and forms a part of the Tripura-Mizoram accretionary belt. A large number of landslides occur every year in this hilly terrain particularly during monsoon. Thus landslides are one of the serious problems of geo-environmental nature in this area rendering the geo-environment of the area in and around Aizawl city extremely fragile. Several landslides of devastating nature have occurred in the study area during the recent past. These include Sihphir landslide (1983), South Hlimen landslide (1992), Vaivakawn landslide (1993); (Plate 1.1(a)), Bawngkawn landslide (1996), Sairang landslide (2001), Venghnua debris flow
(2002); (Plate 1.1(b), Ramhlun landslide (2002); (Plate 1.3(a)), Mission Vengthlang (2003); (Plate 1.2(a-b), Chawnpui landslide (2008); (Plate 1.4(a-b), Venghlui landslide (2008); (Plate 1.3(b)), Armed Veng South (2008, 2009, 2010), Fourlane landslide (2009); (Plate 1.5(a-b)) and Dinhar landslide (2010) and Sihpui (Armed Veng) land subsidence (since ~1993) and Hunthar land subsidence (since ~1995). These have caused considerable loss to human life and property, disruption of vehicular traffic and have adversely affected the geo-environment of the area. The occurrence of these landslides may be attributed to young geology, neo-tectonic activities, steep slope, high relief, high rainfall and improper land use practices (Tiwari et al., 1996a). Some of the landslides may be seismically induced also as the area falls in high seismic zone. It is imperative, therefore, landslide hazard zonation map need to be prepared for planning and execution of development projects and some of these landslides need to be investigated thoroughly in order to decipher the causes and mechanism of failure, and to suggest control and remedial measures. The quantitative determination of the stability of slopes must be based on the knowledge of (a) geological structure of the area (b) the detailed composition and orientation of the strata, and (c) the geomorphic history of the land surface (Zaruba & Mencl, 1982; Sah et al., 1994). Other significant factors like strength properties of rocks and soils constituting the slope, prevailing land use practices, rainfall and earthquakes should also be known in detailed to achieve the above objectives.

Interference with the existing slopes to carry out development schemes without regard to their geo-environmental attributes generally leads to landslides. These attributes for the slopes of Mizoram are less studied. Therefore, planning and subsequent execution of development schemes in the state results into various kinds of mass movements. Although landslides cannot be prevented from occurring, their impact can be minimized through suitable measures by reducing their frequency and severity (Mehrotra et al., 1993). Preparation of landslide hazard zonation maps based on geo-environmental factors of the slopes may be the first step in this direction. These maps divide the land surface into zones of varying degrees of stability and provide clues for coping with the disastrous affects of landslides. Moreover, these are useful in the selection of proper land use practices such as settlements, communication network, dams, agriculture, horticulture and forestry. In advance countries such maps are pre-requisite and planning and execution of different
development projects. Therefore the objectives of the present study include landslide hazard zonation map of the study area in and around Aizawl City on 1:50,000 scale and detailed investigations of some selected landslides in and around Aizawl city.

1.2 LOCATION AND ACCESSIBILITY

The State of Mizoram is located in the southeastern corner of the Northeastern India and is located between N 21° 58’ – N 24° 35’ Latitudes and E 92°15’ - E 93° 29’ Longitudes. Tropic of Cancer passes through the middle of the State through Thenzawl Town. It is bordered by Myanmar to the east and south, Tripura state of India to the upper western half and Bangladesh to the lower western half, Cachar district of Assam to the north and Manipur to the north-east (Fig. 1.1).

![Map of Mizoram](image)

**Fig. 1.1: Location Map of Mizoram**
It has an inter-state boundary of 123 km with Assam, 66 km with Tripura and 95 km with Manipur. Mizoram has a strategic location sharing an international boundary with two foreign countries, namely, Bangladesh (275 Kms) and Myanmar (475 Kms). The state covers a total geographical area of 21,087 sq. km. The entire state is a hilly terrain covered by hill ranges running mostly north - south direction parallel to each other and arranged in en-echelon manner. In between the hill ranges, one can see narrow valleys and deep gorges. The average height of the hills is about 900 metres above sea level. The State comprises of eight districts, namely, Lunglei (4,538 sq.km.), Aizawl (3,576.31 sq. km.), Champhai (3,185.83 sq. km.), Mamit (3,025.75 sq. km.), Lawngtlai (1,991 sq. km.), Saiha (1,965.81 sq. km.), Serchhip (1,421.60 sq. km.) and Kolasib (1,382.52 sq. km.). Each district is under the charge of the Deputy Commissioner. For administrative purpose, the State is divided into 23 Sub-Divisions, 26 Rural Development Blocks and 3 Autonomous District Councils (Mizoram Pollution Control Board and Ministry of Environment and Forest, 2005).

According to 2001 Census, the total population of Mizoram stood at 8,88,573 which accounts for 0.08 percent of the population of India. The decadal population growth rate during 1991 - 2001 is 28.8 percent. In Mizoram, urbanization is taking place at an accelerated pace. Urban population constitutes 4,41,006 while rural population accounts for 4,47,567. The density of the population is 42 persons per sq.km as against the national average of 324 persons per sq.km. Sex ratio is of 933 females per 1,000 males. The majority of the population professes Christianity and 86.97 percent of the total population is Christians.

Landslide is the major natural hazard in the state and the state is also prone for earthquake hazard. Most of the villages and towns including the capital city of Aizawl in the state are located on the top and two sides of the steeply sloping hill ranges (Nandy, 2006). Aizawl city is the district headquarters of Aizawl district. It is located in the northern part of Mizoram and is situated in the central part of Aizawl district. It lies in between 92° 39' to 92° 47' E and longitudes and 23° 39' to 23° 50' N latitudes (Fig. 1, 2). It falls under Survey of India Toposheet Numbers 84/9, 10, 13 and 14. The city is linked by National Highway 54 with Silchar, one of the district headquarters in Assam at a distance of 180 km. It is also connected by a road with Churachandpur, a district headquarter in Manipur and with Agartala, the state capital of Tripura and also
with the neighboring countries of Myanmar and Bangladesh. Lengpui Airport situated at about 30 km to the west of Aizawl city is linked with regular air services to and from Kolkata, Guwahati and Imphal.

![Location map of the study area](image)

**Fig. 1.2: Location map of the study area**

**1.3 CLIMATE**

Mizoram has a mild and very pleasant climate. The average temperature during winter is ~ 11°C and it ranges between 20°C-35°C in summer. The climate of Mizoram is mainly controlled by its location, physiography, pressure regime in warm and moist maritime tropical air masses from the Bay of Bengal and local mountain and valley winds. In addition, the Chin Hills, Arakan Yoma Hill Tracts and Chittagong Hill Tracts also play an important role in shaping the climatic conditions of the State (Das, 1970). Aizawl city enjoys a moderate climate owing to its tropical location. It is neither very hot nor too cold in summers and winters respectively.
Aizawl city and its surrounding areas fall under the direct influence of the south-west monsoon. It rains heavily from May to September. September and October are the autumn months when the rains cease and the temperature is usually between 19°C and 25°C. As such the area receives an adequate amount of rainfall, about 254cm annually, which is responsible for a humid tropical climate characterized by short winters and long summers. The southern part of Mizoram experiences more rainfall (350 cm per year) as compared to northern part that receives about 208 cm of rainfall per year (Mizoram Polution Control Board and Ministry of Environment and Forest, 2005).

1.4 DRAINAGE

The drainage system of the state is governed mainly by the undulating topography and the arrangement of hill ranges and river valleys. Most of the rivers originate from the middle of the state and then run either towards north or south implying that the central part of the state has higher altitude. The important northerly flowing rivers are Tlawng (= Dhaleswari), Tuirial (= Sonai), Tuirini, Tuivawl and Tut (= Gatur) whereas the main southerly flowing ones are Mat, Chhimsuipui (=Kolodyne) and Khawthlangtuipui (=Karnaphuli). These rivers are mostly strike valleys running in between the two hill ranges in the North-South direction. The tributaries of the main rivers flow in Fast-West, NW-SE and NE-SW directions. Some of the rivers, like Mat, follow faults

The drainage system of the study area may be divided into two parts according to the geomorphology of the area, viz. eastern drainage system which flows more or less eastwards joining the Tuirial River and the western drainage system which flows into the Tlawng River. The eastern flank of the city is mainly drained by Chite lui (=stream), Muthi lui and Tuipawl lui that flow eastward and join Tuirial River in the east. The drainage patterns in this area are mainly dendritic to sub-dendritic. Chite lui is the most important single stream of the eastern drainage system as nearly two-third of the eastern slope of the hill range is drained by it. This stream follows a prominent faulted course that can be easily picked up in the Toposheet and Imagery. The western portion of the city is drained by a number of streamlets which join Serlui at the lower level in the south west. Serlui flows in the northwesterly direction and ultimately joins
Tlawng River. Parallel to sub-parallel drainage patterns are seen in the south-western slope of the study area.

1.5 FLORA AND FAUNA

The tropical evergreen forests are found in Mizoram. The State has one of the most enchanting hilly terrains with natural beauty, rich in flora and fauna. The forest clad mountains, covered with mixed variety of vegetation, bamboos, wild banana trees, wild grasses of different varieties, dense woods festooned with wild creepers and canes, orchids of various kinds and wild flowers add to the beauty of the enchanting landscape. The forest cover in the state is about 18,430 sq.km (i.e., 87.42 percent of the State’s geographic area) according to “State of Forest Report -2003” (published by the Forest Survey of India, Ministry of Environment & Forest, Govt. of India). Out of this 84 sq. km is very dense forest, 7,404 sq. km is moderately dense forest and 10,942 sq. km is open forest covers

Mizoram was the denizen of a number of wild animals once. But the population dwindled at an alarming rate due mainly to the age old practice of shifting cultivation involving cutting and burning of vegetation, excessive and uncontrolled hunting and forest fire. Today only marginal and vanishing forms of fauna are left whose future is very deemed and uncertain due to wanton destruction of their habitats. This is the reason why the available wild animals live only in the interior of forests to avoid unfriendly treatment from their superior creature. Keeping in view the future development and habitats of wild animals the government of Mizoram felt the need to create safe havens for animals. Thus, the government created eight protected areas (Pas), viz. Dampa Tiger Reserve (500 sq. km), Murlen National Park (100 sq.km.), Ngengpui wildlife sanctuary (110 sq.km), Phawnpui National Park (50 sq.km.), Khawnglung wildlife sanctuary (35 sq.km.), Lengteng wildlife sanctuary (60 sq.km.), Tawi wildlife sanctuary (35 sq.km.), and Thorang wildlife sanctuary (50 sq.km.). Even for the faunistic composition of the state, no systematic survey has been conducted as yet. However, like the other North-East Indian states Mizoram is also rich in wildlife. Seven species of non-human primates’ viz. hoolock gibbon (Hylobates hoolock), Phayre’s leaf monkey or Dawr (Presbytis phayrei), Assamese macaque (Macaca assamensis), Capped langur (Trachypithecus pileatus),
Stumptailed macaque (*Macaca arctoides*), Rhesus macaque (*Macaca mulata*) and the slow Lorries (*Nycticebus coucang*) are found (Ministry of Environment and Forest, 2005).

Among the cats, the tiger (*Panthera tigris*), leopard (*Panthera pardus*), clouded leopard (*Neofelis nebulosa*), golden cat (*Catopuma temmincki*), leopard cat (*Prionailurus bengalensis*), Jungle cat (*Felis chaus*) are known to exist in the state. Among the civets, the small Indian binturong (*Arctictis binturong*) is found. Other smaller mammals such as hog badger (*Arctonyx collaris*), chinese ferret badger (*Melogale moschata*), crab eating mongoose (*Herpestes urva*), Indian flying fox (*Pteropus giganteus*), common giant flying squirrel (*Petaurista petaurista*), Malayan giant squirrel (*Ratufa bicolor*), etc. are also found. So far, 42 species of mammals from 18 families, 13 species of amphibians from 4 families, 37 species of reptiles from 10 families and 201 species of birds from 46 families have been recorded (Zonunmawia, *et al.*, 2004).

### 1.6 REVIEW OF LITERATURE

India is vulnerable to different natural hazards due to its proximity to geodynamically active locales and unique climatic pattern. Both these factors in different combinations lead to the occurrence of disasters resulting from natural hazards like floods, earthquakes, draughts, cyclones and landslides in different parts of the country at frequent intervals. Landslides are one of the natural hazards that affect at least 15% of land area of our country exceeding 0.49 million km². Landslides of different types occur frequently in geodynamically active domains in Himalaya, Northeastern India as also in stable domains in Western Ghats and Nilgiri Hills of southern India (Sharda, 2004). Several landslide hazard zonation schemes are available in the literature and the methodologies are still being refined. Varnes (1984) presented a comprehensive review of the pioneering work on landslide hazard zonation carried out till early eighties. Several attempts have been made for zonation using different techniques (e.g., Carrara, 1983; Carrara *et al*., 1991; Anbalagan, 1992; Pachauri and Pant, 1992; Juang *et al*., 1992; Van Westen, 1993; Gupta *et al*. 1999). A
reasonably good number of studies have been carried out in different landslide prone zones of the country and the important ones are being summarized here under.

Gupta and Joshi (1990) carried out Landslide Hazard Zoning using GIS approach from the Ramganga catchment, Himalayas. They stated that apart from the factors like land use, tectonic features and local features like places of sharp river bends, areas under-cut by streams and toe-cuttings, seismicity and precipitation are the other two important factors which have significant bearing on landslide activity in this area.

Gupta et al., (1993) prepared Landslide Hazard Zonation map of the upper Satluj valley, Kinnaur district, Himachal Pradesh. They found out that 13 per cent of the total area falls in very high hazard zone, 10 per cent in high hazard zone, 34 per cent in moderately hazard, 34 per cent in low hazard and only 9 per cent in very low hazard zone.

Sarkar et al., (1995) carried out the Landslide Hazard Zonation study in Garhwal Himalaya. They observed that the very high and high instability zones are nearer to the North Almora Thrust; obviously due to the tectonically active nature of the thrust and also due to the presence of loose powdery rocks as a result of the shearing effect. They also confirmed that most of the landslides are located in the very high and high grade instability zones.

Sharma and Kandpal (1996) carried out Landslide Zonation mapping in parts of Garhwal, Himalaya and concluded that significant influence of the anthropogenic activity has been reflected by the higher percentages of the high and the moderate landslide categories in Uttarkashi-Chinyali Saur sector as compared to Thati Katu-Maneri sector, as the former has comparatively more human activity. They also observed that the cataclinal slopes had lesser number of failed slopes.

Rawat et al., (2004) studied the slope failure of Banjarimai landslide, Chhindwara district, M.P. using geomorphological techniques and concluded that the causes responsible for slope instability in the area are the intense precipitation during monsoon that causes over saturation of the slope material as a result shearing strength of the slope forming materials are reduced considerably leading to their failure.
Moreover geological structures like bedding and joints also reduce the strength of the rocks and thus disturb the equilibrium of the slopes.

Sarkar and Gupta (2005) carried out landslide hazard zonation in Srinagar-Rudraprayag area of Garhwal Himalaya. They concluded that the study of relationships between the landslides and the terrain factors has revealed the contribution of the factor categories in landslide occurrence. Amongst all the rock types present in the area, phyllites are found to be most landslides prone.

Muthu and Muraleedharan (2005) studied the causes and mechanism of failure of Amboori landslide, Thiruvananthapuram district, Kerala and found out that this landslide is a classical example of planar failure along lithomargic clay that defines the contact between bedrock and the overburden.

Naithani, (2007) carried out Macro landslide hazard zonation mapping using univariate statistical analysis in a part of Garhwal Himalaya. He found out that the geological structures and lithology have accounted for more than 72 percent of all the observed landslides in this part of Himalaya.

Sreekumar et. al., (2009) studied the slope instability from Idukki District, Kerala. He stated that the problem of instability of slopes is severe in many parts of Western Ghats. Occurrence of landslides is frequent in the Idukki district of Kerala State particularly along road cuttings and hill slopes. The main rock types in this area are hornblende granite and lateritic rocks which are highly weathered. A very high incidence of landslides in this district was mainly due to the weathering of rocks, presence of joints that traverse the rock, ground water and the weak cohesive property of laterite rocks.

The hilly and rugged terrain of Mizoram is also very prone for landslides and a large number of slope failures occur every year in this state particularly during monsoon. This is primarily due to young geology, tectonic activity, high slope and relief, heavy rainfall and improper land use practice in the state Tiwari et.al., (1996a). Landslide studies carried out so far in the state are mentioned below.
Chouhey and Lallenmawia, (1987) attempted to assess the landslides in the area of Electric Sihpui Veng, Armed Veng, Sarawn Veng and Vaivakawn in Aizawl city, Mizoram based on field and laboratory investigations. They observed the different geological setting and structural control, effect of tectonic movement of the region emphasizing on the causes and effects of sliding phenomenon. They also studied strength characteristics, pore pressure, effective stress and erosion conditions of the material at toe of the slopes at these localities.

Tiwari et. al., (1996a) carried out geotechnical appraisal of the Bawngkawn landslide, Aizawl. They inferred that the failure occurred along the critical joint plane and main cause of this is diverse topographical, geological and structural settings. Tiwari et. al., (1996b) for the first time prepared Landslide Hazard Zonation Map (LHZ) along Hrangchal-kawn – Rotlang road section in the Lunglei district of Mizoram following Landslide Hazard Evaluation Factors Rating Scheme (LHEF) of Anhalagan (1992). They covered about 119.35 sq. km of the area on both the sides of this road section. The LHZ map prepared by them shows that Very Low Hazard Zone does not occur in the area, Low Hazard Zone covers about 3.575 sq. km and Very Low Hazard Zone covers about 3.325 sq. km. Moderate Hazard and High Hazard Zones occur in most of the area and cover about 42.65 and 69.80 sq. kms area respectively.

Kumar et. al., (1996) studied the problems of instability at South Hlimen Quarry site in Mizoram. They were of the opinion that the acute instability problem in South Hlimen Quarry is stemming from two main factors, viz., (i) large size of individual blocks and (ii) the smooth joint surfaces. The tropical climate and heavy rainfall might have caused an additional decrease in the cohesive strength of the joint planes. Additionally, shaly intercalations between sandstone beds might have provided active slippage surface of failure.

Tiwari and Kumar (1997) studied the disastrous landslide of 1992 at South Hlimen, 7 Km north of Aizawl city. They stated that the slope stability problem in the area is mainly due to blocky nature of the sandstones. The blocks of sandstones are formed as a result of intersection of N-S trending bedding planes and E-W trending
vertical joint planes. Owing to toe cutting and excessive use of explosives (for quarrying purpose) these blocks were subjected to free fall along the bedding planes.

Tiwari, and Kakhabra (1997) conducted landslide studies in Lunglei district of Mizoram. The basic aim of this study was to prepare Landslide Hazard Zonation map along the major road sections of Lunglei district of Mizoram on 1:50,000 scale. Beside a geotechnical investigation of a few major landslides was also carried out. A landslide inventory map of the district was also prepared. Zonation studies have been carried out on both sides of the road sections (both uphill and downhill slope) covering an area of about 604.275 sq. km. These maps show that, Very Low Hazard Zone do not occur in the area whereas Very High Hazard Zones occur only in 3.300 sq. km of the area. The Low, Moderate and High Hazard Zones cover 101.100 sq. km, 298.550 sq. km and 201.325 sq. km of the area respectively.

Raju et. al., (1998) conducted Landslide Hazard Zonation studies in southern part of Mizoram. They prepared preliminary Hazard Zonation Map of 6,700 sq.km area. They estimated that about 10 percent of the area falls under High Hazard Zone, 60 percent area in Medium Hazard zone and the rest 30 percent falls in the Low Hazard Zone. Tiwari et. al., (1998) attempted Landslide Hazard Zonation mapping along Hnahthal – Hrangchakhawn road section in Lunglei district of Mizoram. They mapped 104.32 sq.km of the area on the up and down hill slopes along this road. The map shows presence of low hazard, medium hazard and high hazard zones occurring 26.85, 51.17 and 26.30 sq. km. of areas respectively.

Lawmkima et. al., (in press) conducted geomechanical analysis of Sairang landslide near Aizawl, and inferred that this landslide was mainly due to the presence of bedding shears and clay pockets/beds with swelling and shrinkage properties. This in conjunction with the poor shear strength of the slope forming material in natural moisture content caused frequent slope failure at this locality. Further, decrease in the shear strength of overburden and bed rocks during rainy season due to water saturation also contributed significantly to the frequent failure of slope at this locality. Frequent lithological variations occurring in the study area might have led to frequent change in the stability conditions.
1.7 OBJECTIVES OF THE PRESENT STUDY

The objectives of this research are as follows:

1. Preparation of thematic maps with lithological, structural, slope, slope-aspects, relief, hydrological, land use/land cover maps on 1:50,000 scale in GIS environment.

2. Preparation of Landslide Hazard Zonation map.

3. Detail investigation of some selected landslides (case study).


1.8 TYPES OF LANDSLIDES

Landslide is one of the geological hazards which is more frequent and wide spread than any other hazards. Vulnerable impact of this hazard on the economy, hardship and danger for the people is well documented in different parts of the world.

Landslides are among the most important processes of a catastrophic type that lead to modification of the surface morphology. They are defined as “abrupt, short – lived geomorphic events that constitute the rapid motion end of the mass movement spectrum” (Coates, 1977). Other terms used to denote this process are “landslip” and “mass-wasting”. They include displacement of slopes forming earth material by fall topple, slide or flow due to gravity (Zaruba and Mencl, 1969; Varnes, 1978).

The term ‘landslide’ includes all varieties of mass movements of hill slopes and can be defined as the downward and outward movement of slope forming materials composed of rocks, soils, artificial fills or combination of all these materials along surfaces of separation by falling, sliding and flowing, either slowly or quickly from one place to another. Landslide is a general term for a wide variety of downslope movements of earth materials that result in the perceptible downward and outward movement of soil, rock, and vegetation under the influence of gravity. The material may move by falling, toppling, sliding, spreading, or flowing.

Landslides can be classified on the basis of the mode and rate of the movement, the shape of the slide surface, the type of material involved and a number
of other criteria (Zaruba, and Menel, 1982). Abbot (2004) classified sliding movements according to the material displaced and the type and rate of movement, and studied the relationships between mass movements and geomorphological cycles and climate factors (Table 1.1). Later Soetoers and Van Westen, (1996) gave new types; topple and spread.

Table 1.1: Classification of mass movement (after Abbot, 2004)

<table>
<thead>
<tr>
<th>Type of Movement</th>
<th>&lt; 1 cm a year</th>
<th>1 mm/day to 1 km/hour</th>
<th>1 – 5 km/hour</th>
<th>Generally &gt;4 km/hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow</td>
<td>Slowest</td>
<td></td>
<td>Fastest</td>
<td></td>
</tr>
<tr>
<td>Creep/debris</td>
<td></td>
<td>earth flow</td>
<td>mudflow (water saturated debris)</td>
<td>debris avalanche (debris)</td>
</tr>
<tr>
<td>Slide</td>
<td>Rotational</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Translational</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fall</td>
<td></td>
<td>Rock fall (bed rock)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Debris fall (Debris)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>landslides</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1.8.1 Falls

These types occur in very steep slope when elevated masses are separated along joints, bedding or other weak planes. Rock falls starts with the detachment of rock from a steep slope along a surface on which little or no shear displacement takes place. The detached material then descends mainly through the air by falling,
bouncing, or rolling. Movement is very rapid to extremely rapid (Fig. 1.3, 1.4). Rock falls are very common and in most cases they are easily identifiable. Falls are strongly influenced by gravity, mechanical weathering and presence of interstitial water.

Fig. 1.3: Sketch of rock fall site

Fig. 1.4: Sketch of typical rock fall site

1.8. 2 Flows

Flows are the type of movements with a fluid motion. The speeds of the movements vary from slow to rapid. In the first type, failure is not easily perceptible.
The ground may be moving down slope at such slow rates as a few centimetres a year or even less. In rapid flow type, however, the movement of failing mass may be easily visible and the mass may travel a few meters or more a day (Fig. 1.5). The ranges of material are differently graded from massive boulder to sand, clay, snow and ice. The difference between slide and flow are based on the water contents and slip surface. There are several sub-types of flows such as earth-flow, mudflow, debris-flow, and debris avalanche. Generally, they occur during intense rainfall on water saturated soil. They usually start on steep hillsides as soil slumps or slides that liquefy and accelerate to speeds as great as 56 km per hour. Multiple debris flows that start high in canyons commonly funnel into channels. There, they merge, gain volume, and travel long distances from their source. Flows also begin in swales (depressions at the top of small gullies) on steep slopes making areas down slope from swales particularly hazardous. Road-cuts and other altered or excavated areas of slopes are particularly susceptible to debris flows. Debris flows and other landslides onto roadways are common during rainstorms, and often occur during milder rainfall conditions than those needed for debris flows on natural slopes. Areas where surface runoff is channeled, such as along roadways and below culverts, are common sites of debris flows and other landslides.

![Fig. 1.5: Two views of debris flow environments](image)

1.8. 3 Slides

Slides can be defined as movements of masses on failure surfaces or on the zone of shear strain. Typically failure surfaces are either 1) curved in convex upward sense (rotational slides) and 2) nearly planar (translational slides).
1.8.3.1 Rotational Slides

The slides occur along a curved surface. In the crown parts, the displaced masses moves downward vertically and the top surface of displaced masses angles back toward on the scarp. Movement is more or less rotational on axis parallel to the slope (Cruden and Vernes, 1996). In rotational slides, the failing surface is generally curved and concave in character and the speed of failure is also quite rapid. If the surface of rupture is circular the displaced mass may move along the surface with little internal deformation. Rotational slides occur most frequently in homogeneous materials. Because of nature of the failing surface, the movement of the mass takes the form of a sort of rotation, rather than translation. The material involved in failure tilts at the rear end and heaves up at the front or toe (Fig. 1.6). There may be single surface of failure or a number of them adjoining to each other (Singh, 1994)

1.8.3.2 Translational Slides

Translational slides are type of slides where the sliding can extend downward and outward along a broadly planar surface, and slide out over the original surface (Cruden and Vernes, 1996). This type typically takes place along structural features, such as bedding plane or the interface between resistant bedrock and weaker overlying material. They are found globally in all types of environments and conditions (Abbot, 2004.). Translational slides generally fail along geologic discontinuities such as faults, joints, bedding surfaces, or the contact between rock and soil. These slides typically reflect a weak layer or existing structural discontinuity (Cruden and Vernes, 1996). If the overlying material moves as a single, little-deformed mass, it is called a block slide. The surface of failure is generally planar in character, speed of failure is quite rapid and the nature of mass involved in failing may be rock slabs, debris and soil cover or even a mixture of all of them (Fig. 1.7, 1.8). These slides are quite frequent on slopes made up of rocks and cohesive soils (Singh, 1994)
Fig. 1.6: Rotational Slide

Fig. 1.7: Translational Slide

Fig. 1.8: Cross-section of a translational slope failure
1.8.4 Topples

Toppling is privileged by the presence of a steeply inclined joint set with the strike aligned by more or less parallel to the slope face. Topples are similar to falls except that the initial movement involves a forward rotation of the mass. Rock toppling occurs when one or more rock units rotate about their base and collapse (Fig. 1.9, 1.10).

![Diagram of rock toppling](image)

**Fig. 1.9: Rock toppling**

![Diagram of rock toppling process](image)

**Fig. 1.10: Rock toppling process**
1.8.5 Spreads

The term spread describes sudden movements on water-bearing seams of sand or silt overlain by homogeneous clays or loaded by fills. Lateral spreading occurs when the soil mass spreads laterally and this spreading comes with tensional cracks in the soil mass. Spread is the distinctive type of landslide. This type generally takes places on very gentle slope or flat terrain. The upper layer is broken and moves outward on the underlying layer. The surface’s boundaries of mass movement can be difficult and diffuse to recognized (Soeters and Van Westen, 1996). The failure is usually triggered by ground motion, such as that experienced during an earthquake, but can also be artificially induced (Fig. 11).

![Sketch of lateral spreading](image)

**Fig. 1.11: Sketch of lateral spreading**
Plate 1.1

Plate 1.1a: Valvakawn landslide (1993)

Plate 1.1b: Venghnuai debris flow (2002)
Plate 1.2a: Mission Vengthlang landslide (2003) - view from the crown

Plate 1.2b: Mission Vengthlang landslide (2003) - synoptic view
Plate 1.3

Plate 1.3a: Ramhlun landslide (2002)

Plate 1.3b: Venghlui landslide (2008)
Plate 1.4

Plate 1.4a: Chawnpui landslide (2008) (view from the west)

Plate 1.4b: Chawnpui landslide (2008) (view from the east)
Plate 1.5

Plate 1.5a: Fournie landslide (2009)

Plate 1.5b: Fournie landslide (2009)