Chapter 12

MASS WASTING

12.1 INTRODUCTION

Mass wasting is a general term for a variety of processes by which large masses of earth materials are moved under gravity, either slowly or quickly, from one place to another. The term landslide is commonly used to denote the downward and outward movements of slope-forming materials along surfaces of separation by falling, sliding, and flowing at a faster rate. Although landslides are primarily associated with mountainous regions they can also occur in areas of low relief, especially in surface excavations for highways, buildings and open-pit mines. The geological history and human activities often cause unstable conditions that lead to slope failures.

12.2 TYPES OF MASS MOVEMENT

Table 12.1 shows the classification of slope movements (Varnes 1978) on the basis of the nature of the movement and the type of material involved in the process. Tables 12.2, 12.3, and 12.4 show the nature of hill slope processes in mountainous terrain along with geotechnical aspects, surveys, and remedial works.

12.2.1a *Falls*

Falls are abrupt movements of slope materials that become detached from steep slopes or cliffs. Movements occur by free fall or a series of leaps and bounds down the steep slope. The relatively free character and lack of a slide plane differentiates the rockfall and rockslide. Depending upon the type of slope materials involved, it may be a rockfall, soil fall, debris fall, earthfall, boulder fall and so on (Table 12.2).

12.2.1b *Topples*

A topple is a block of rock that tilts or rotates forward on a pivot or hinge and then separates from the main mass falling on the slope and subsequently bouncing or rolling down the slope.

12.2.1c *Slides*

The term slides refers to the mass movements with a distinct surface of rupture or zone of weakness separating the slide material from the more stable underlying materials (Tablea 12.2 and 12.3). The two major types of slides are **rotational** and **translational** slides.

Rotational Slides

Rotational slides occur on slopes of homogeneous clay or shale and soil slopes. The slide movement is more or less rotational about an axis that is parallel to the contour of the slope. The scarp at the head may be almost vertical, while the toe bulges upwards and sometimes flows out.

Translational Slides

Translational slides are mass movements on a more or less planar surface. The movement of translational slides is controlled by surfaces of weakness such as bedding planes, joints, and faults. Slide materials may range from loose unconsolidated soils to slabs of rock.

Block Slides

Block slides are translational slides in which the moving mass consists of a single unit of rock block that moves down slope.

12.2.1d ***Spreads***

The failure in this case is caused by liquefaction, the process whereby saturated, loose, cohesionless sediments are transformed into a liquefied state. Rapid ground motions such as earthquakes usually trigger the failure.

12.2.1e ***Flows***

Creep

A creep is an imperceptibly slow, steady, downward movement of slope forming soil or rock. The movement is essentially viscous enough to produce permanent deformation but too small to produce failures as in landslides. A creep is indicated by curved tree trunks, bent fences or retaining walls, tilted poles, and small soil ripples or ridges.

Debris Flow

Debris flow is a form of rapid mass movement involving loose soil, rocks, and organic materials along with entrained air and water to form a slurry that flows downslope. In general, five conditions are important for the debris flow to occur. They are :

i) steep slopes
ii) loose rock and soil materials,
iii) clay minerals,
iv) saturated soils, and
v) rainfall or snowmelt generated runoff of sufficient intensity and duration to initiate slope movements. For more details, refer to Section 13.3.3 in Chapter 13.

Debris Avalanche

A debris avalanche is a type of very rapid to extremely rapid debris flow.

Earth Flows

Earth flows have a characteristic bowl-like depression at the head where the slope material becomes liquefied and flows out. The flow is usually channelised on the slope and spreads out at the toe. The flow generally occurs in fine-grained materials or clayey rocks under saturated conditions.

Mudflows

Mud flows are a type of earth flow consisting of material containing about 50 per cent of sand, silt, and, clay-sized particles that are well saturated and flow rapidly.

12.2.1f *Complex Movements*

Slope movements involving two or more principal types of movement are called complex movements. For example rolling rock blocks from higher elevations due to rockfalls may cause debris slides at lower elevations. Often landslide dams are formed because of a combination of movements of some of the following types - rock and earth slides, debris and mudflows, and rock and debris avalanches.

Table 12.1 Abbreviated version of Varnes' classification of slope movements

TYPE OF MOVEMENT			TYPE OF MATERIAL		
			BEDROCK	DEBRIS	SOILS
				Predominantly coarse	Predominantly fine
FALLS			Rock fall	Debris fall	Earthfall
TOPPLES			Rock topple	Debris topple	Earth topple
SLIDES	ROTATIONAL	FEW UNITS	-	Debris slump	Earth slump
			Rock block slide	Debris block slide	Earth block slide
	TRANSLATIONAL	MANY UNITS	Rockslide	Debris slide	Earth slide
SPREADS			Rock spread	Debris spread	Earth spread
FLOWS			Rock flow	Debris flow	Earthflow
			(deep creep)	(soil creep)	
COMPLEX			Combination of two or more principal types of movement		

Source: Modified from Varnes 1978

12.3 CAUSES OF LANDSLIDES

The various causative factors of landslides are listed below.

12.3.1 *Natural Factors*

a. High relief or steep slopes.

b. Undercutting of the banks by deeply incised rivers and streams.

c. Extensive development of weak rocks such as phyllites, slates, and schists; presence of calcareous interlayers in these rocks which leads to high porosity and void formation due to leaching and dissolution.

d. Heavily fractured rocks because of intense folding and faulting. As many as four systematic sets of fracture plus other random and stress relief joints are very common in mountainous countries.

e. High weathering of the rocks.

f. Concentrated precipitation.

g. Seismic activity. The Himalayan Range lies in a high seismicity belt. Several active faults have been mapped. Landslides due to seismic loading are very common.

12.3.2 *Anthropogenic Factors*

a. Deforestation

Intensive deforestation has taken place in most parts of the *Himalaya*, excepting the *Higher Himalaya*, in the last decades.

b. Improper Land Use

This includes:

- agricultural practices on steep slopes,
- irrigation on steep and vulnerable slopes,
- overgrazing, and
- quarrying for construction material without considering the conditions of the terrain.

c. Construction Activities

Improper or total lack of terrain capability evaluation before placement of infrastructure on hill roads and canals, located in areas with high slope instability, with the result that hazards are common. An unlined canal across a potential or active landslide or road cut in the tow of ancient landslide deposits are seen in many places. Maintenance of other infrastructures is either non-existent or very poor.

12.4 MAIN TRIGGERS OF MAJOR LANDSLIDES AND THEIR CONTROL

Landslides are the result of the interaction of geological and geographical environment. Earthquakes and rainstorms constitute two of the most important landslide-inducing agents.

12.4.1 *Earthquake-induced Landslides*

Earthquakes usually cause many large-scale landslides, some of which block rivers forming lakes. China is a country that has had many earthquakes. From 780 B.C to 1976 A.D., there have been as many as 656 earthquakes of $M > 6.0$. Earthquake-induced landslides were caused by 33.5 per cent of the total shocks in China, excluding earthquakes in marine areas, in Xizang and Taiwan (Feng and Guo 1985). Apart from the earthquakes themselves (i.e., seismic accelerations, duration of shock, focal depths, and angle and direction of the approach of seismic waves), the environmental factors, such as geology and landform, play a important part in the formation of landslides induced by earthquakes. This is why some smaller earthquakes induced far more landslides than other large earthquakes. Geological structure and the lithological character of rocks influence the landslides. Landslides are commonly seen on the slopes and spurs of mountains cut by faults. On slopes consisting of loosened limestone and igneous rocks, falls occur readily, but on slopes consisting of claystone, shale, and phyllite, falls are few in number.

The type of slope and the slope angle have a great influence upon landslides and falls. Straight slopes seldom have landslides and falls, but they are, however, common on the convex, concave, and complex slopes. The places where the landslides or falls occur are mostly steeper areas of slopes. The statistical data gathered from the earthquake areas of China from 1973 to 1976 give us part of the story: landslides were not found on slopes with a slope angle of less than 25°.Ninety per cent of the landslides occurred on slopes with a slope angle ranging from 30° to 50°. In most cases, falls happened on slopes with a slope angle of 67° - 75°. Such figures would be of great help in selecting a relative safety zone in an earthquake prone area. The relative safety zone should be in a region with a slope angle of less than 25° in the mountains.

Earthquakes have acted as triggers to many landslides and ground failures in some parts of Nepal. The landslides in Bhajang can be cited as examples. The mountainous parts show seismically triggered slumps, debris slides, and rockfalls, whereas the Terai Region suffers from spreads, liquefaction, quicksand conditions, and sandboils. Moreover, there is evidence of landslides taking place during the following monsoon from colluvium loosened by the previous year's earthquake. Apart from these, the critical stage of toe undercutting of marginally stable slopes, especially with the older slide deposits, by floods and debris torrents as well as breaching of landslide dams, can be taken as secondary landslide triggers.

12.4.2 *Rainfall-induced Landslides*

Rainfall is another important landslide trigger. There is a direct correlation between the amount of rainfall and the incidence of landslides, as indicated below.

a. If cumulative precipitation of the area amounts to about 50 mm to 100 mm in one day, and daily precipitation is more than 50 mm, somewhat small-scale and shallow debris landslides will occur.

b. When the cumulative precipitation over 2 days amounts to about 150 mm, and daily precipitation is about 100 mm, the number of landslides has a tendency to increase with precipitation.

c. When cumulative precipitation exceeds 250 mm over two days and has an average intensity of more than 8 mm per hour in one day, the number of large and vast landslides increase sharply.

12.5 PREVENTION AND CONTROL OF LANDSLIDES

The prevention and control works actually carried out in the landslide areas are based on the following concepts: Firstly, a great deal of importance is placed on human life, secondly, on public structures and buildings, road traffic, and prevention of river flooding if a landslide dams a river. For the sake of convenience, landslides can be arbitrarily divided into two groups; those occurring on artificial slopes and those occurring on natural slopes. The term artificial slope implies not only man-made or constructed slopes but also those that have been partly excavated or formed by human activities. It, therefore, includes levée, dam, reservoir bank, road slope, and mining spoils. Due to their locations, landslides occurring on natural slopes in wildland or forested watersheds receive less attention from the public. These landslides are not usually subject to treatment unless they endanger railways, roads, buildings, reservoirs, or other important installations. The control works for these two kinds of landslide are therefore somewhat different. Of course, some control works can certainly be carried out on both types, but, in general, artificial slopes receive more intense treatment than natural slopes. Measures of landslide control are summarised below.

A. For artificial slopes

a. Avoidance:
Relocation, bridging, tunnelling (or open-cut and cover tunnel).

b. Surface Drainage:
Drainage channels or ditches, prevention of leakages, cleaning natural ditches.

c. Sub-surface drainage:
Drainage tunnels, counterfort trenches, deep-seated counterfort drains, vertical drill holes, horizontal boreholes, slope seepage ditches, drainage wells of ferro-concrete, drainage wells of liner plates.

d. Supporters:
Retaining wall, anchor retaining wall, cribworks, gabions, piling works.

e. Excavation:
Removal, flattening, and benching.

f. River structural work:
   Check dams, revetment, spur dikes.

g. Other methods:
   Vegetation, blasting, and hardening.

B. For natural slopes

   a. River structural work:
      Check dams, revetment, groin, dikes.

   b. Benching and diversion.

   c. Revegetation, grass seeding, afforestation.

12.6 LANDSLIDE-DAMS

The natural damming of rivers by landslides is a significant hazard in many areas. Landslide-damming is particularly common in the high rugged mountains of the Hindu Kush-Himalayan Region. Many landslide-dams have failed catastrophically, causing major downstream flooding and loss of life in this area.

12.6.1 *Causes of Landslide-Dams*

Landslide-dams are common in the steep, narrow valleys of high rugged mountains because these valleys require relatively small amounts of material to form blockages. Landslide-dams can be caused by a broad range of mass movements in different physiographical settings. Most landslide-dams are formed by rock and earth slumps and slides, debris and mudflow, and rock and debris avalanches. A very few have been caused by rock and soil falls or by slope failure (liquefaction) in sensitive clays.

Schuster and Costa (1986) found that the two most important causes behind the initiation of landslide-dams are excessive precipitation (rainfall and snowmelt) and earthquakes. Volcanic eruptions constitute a minor landslide-dam forming process. Other mechanisms, including ice-dam failure, devegetation, and stream undercutting and entrenchment, account for very small percentages of triggering processes. Large landslide-dams are formed by large earth and rockslide/slumps and debris avalanches which commonly occur on steep slopes and attain high velocities that allow stream blockage before the material can be sluiced away by river action. Complex landslides that start as slumps or slides and break up into debris avalanches can also create large dams. The size of landslide-dams ranges in height from only a few metres to hundreds of metres. The size is controlled primarily by the volume of the mass failed down to the valley and the geometry of the valley. Two very large landslide-dams have blocked tributaries of the Yangtze River in Southwest China in this century: (1) the 255 m high Dixie Landslide-Dam, which failed in 1933, causing a catastrophic flood on the Min River that killed at least 2,423 people in three downstream counties, and (2) the 175 m high Tanggudong Landslide-Dam that blocked the Yalong River in 1967 and, upon failure by overtopping, causing a huge flood that travelled 1,000 km downstream (Li 1990).

12.6.2 *Failure of Landslide-Dams*

Landslide-dammed lakes may last for several minutes or several thousand years, depending upon many factors, including volume, texture, sorting of the dam material, rates of seepage through the dam, and rates of the sediment and water flow into the newly formed lake. A study of 73 cases of landslide-dam failure, for which the times of failure are known, indicates that 27 per cent of the dams failed within 1 day of formation; 41 per cent failed within 6 months; and 85 per cent failed within 1 year of formation.

Because of the lack a protected spillway, landslide-dams commonly fail by over-topping followed by breaching from erosion by the overflowing stream. A very small percentage of landslide-dam failures contributes to seepage and piping or slope failure of the dam.

12.6.3 *Floods from Landslide-Dam Failure*

Landslide-dams create the potential for two very different types of flooding: (1) upstream flooding as the dam-lake fills and (2) downstream flooding as a result of the failure of the dam. The threat to life from upstream flooding is minimal because the water-rise behind the dam is relatively slow, but the property damage can be substantial as the basin of the natural impoundment is filled. Downstream floods resulting from the failure of landslide-dams are usually much larger than floods originating directly from snowmelt or rainfall and constitute a significant threat.

In 1841, hundreds of villages and towns were swept away by a large flood resulting from the failure of a landslide-dam at Lichan Gan, on the upper Indus River, North Pakistan. A Sikh army camp, close to the river, about 420 km downstream, was overwhelmed by the flood and about 500 soldiers were killed (Mason 1929).

It is usually possible to estimate accurately the extent and rate of upstream flooding from landslide-dams. Such estimates require knowledge concerning the height of the dam, crest rates of streamflow into the dam-lake, rates of seepage through or beneath the dam, and information on topography upstream from the dam. For the rapid assessment of downstream flood potential, the peak discharge of downstream flooding can be estimated by the regression equation given by Costa and Schuster (1987), namely:

$$Q = 0.063\ PE^{0.42}$$

where,

Q is peak discharge in cubic metres per second and PE is potential energy in joules.

The potential energy is the specific energy of the lake water behind the dam prior to failure and can be computed as the product of dam height (metres), volume (cubic metres), and specific weight of water (9,800 newtons/cubic metre).

12.6.4 *Methods of Preventing Landslide-Dam Failure*

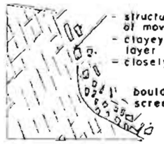
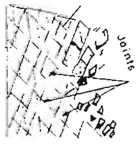
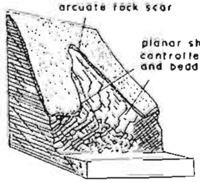
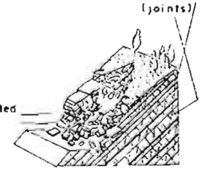
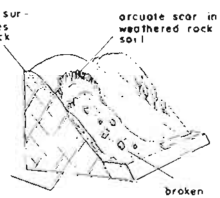
In recent years, construction of control measures has been attempted on many landslide-dams, as soon as possible after formation, to prevent dam failure and subsequent flooding. Spillways are the most simple and most common method. A well-known example of a successful spillway across a landslide-dam is the spillway constructed in 1959 by the U.S. Army Corps of Engineers on the Madison Canyon landslides, Montana (Harrison 1974). Pipes, tunnel outlets, and diversions have also been used to prevent dam failure and control discharge from the landslide-dam lake in many countries. A famous example is the 2,590m long, 3.4-4m diameter gravity-flow outlet tunnel through Tertiary tuffaceous and volcanic flow rocks composing the ridge immediately west of Spirit Lake in the U.S.A. (Sager and Chambers 1986). Excavation of this tunnel was done by TMB (tunnel boring machine) technique. This outlet tunnel permitted the lake level to be drawn down permanently to an elevation of 1,048m resulting in a safe lake volume of approximately 259 million m^2.

In a few cases, large-scale blasting is used to excavate new river channels through landslide dams. In 1984, this technique was used to excavate a channel through the Zhougu Dam on the Bailong River in Gansu Province, China (Li 1990).

12.7 GLACIAL LAKE OUTBURST FLOODS

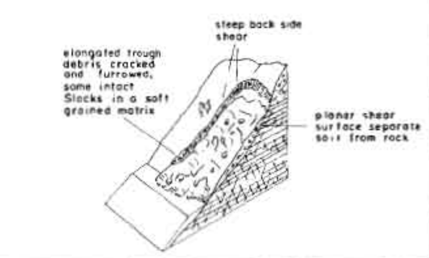
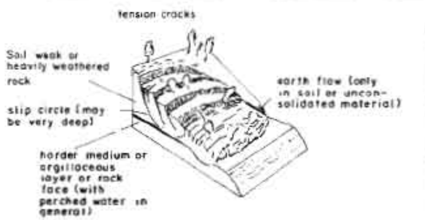
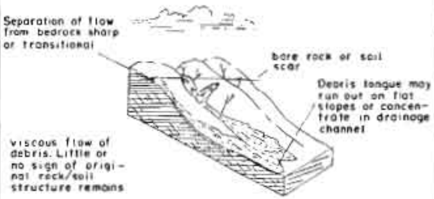
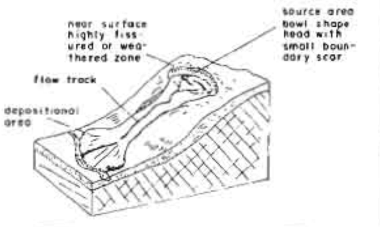
Glacial lake outburst floods (GLOF) are debris torrents resulting from a sudden and catastrophic release of water from a lake of glacial origin. The lakes are usually impounded by glacial ice or moraine. GLOF are generated either by the overtopping of lake water by ice or moraine, or by seepage and piping under these dams, resulting in their ultimate collapse. GLOF are common in glaciated mountain ranges, including the Himalayan Range. There are numerous lakes of glacial origin in the *Higher Himalaya* and all have different morphology, size, and type.

TABLE 12.2 Falls and slides

A–FALLS	CHARACTERISTIC FORM	MATERIAL	MOUNTAIN ZONES	COMMON FACTORS CONTRIBUTING TO INSTABILITY OR EROSION	TYPICAL SLOPE ANGLE	COMMON RATE OF MOVEMENT	SURVEY TOPICS	CONSTRUCTION AND REMEDIAL WORKS
I. Rockfall variant: 1) Toppling 2) Wedge with fall component	 Rockfall planar or with wedge component  topple	Jointed I and M rocks, bedded or jointed S rock like limestone, dolomite, sandstone, soft rock, indurated soil exposed to rapid undercutting parameters C = O at discontinuities ϕ < dip J[1] (in 1.) in 2.: Flexure due to J[1]	Ⓐ Ⓑ sometimes in Ⓒ	1. W enlarging and weakening discontinuities in cliff face 2. P through seepage in joints (and frost/ice action in high altitude) 3. U including general stress relief effects of erosion 4. EQ, blasting	45° to 90°	Extremely rapid	1 Structural study and lithology and 2 permeability estimate	- Slope support - ditch or wall for - debris collection - trimming and scaling
B–SLIDES Translational a. Rock slide 1) wedge slide 2) Plane slide or block glide on bedding or major discontinuity, very often in combination with wedge occurrance in M and S	 	Interbedded S rocks where argillaceous beds aligned parallel to the slope or with a lesser angle. M rocks mostly foliated, I sometimes. Any continuous joint can play the role of shear plane Parameters: C ≅ O at discontinuities 1) ϕ ≤ dip of joints forming wedge intersection 2) I ≤ dip angle of failure plane	Ⓐ Ⓑ sometimes in Ⓒ Frequent in lesser Himalayas	1 W 2 Relation between rock structure and slope producing unfavourable discontinuity pattern 3 U, including stress relief 4 P. (and frost-ice action in high altitude) 5 rock type 6 EQ, blasting The failure hazard increases in both cases when a "fan" of wedge is present besides a central wedge. Planar failures tend to be larger than wedge failures (See Rock and debris slide hazard Mapping....)	30-60° sometimes less for block glides	Moderate to very rapid	1 Structural and lithological study 2 and permeability estimate 3 Brief hydrogeology 4 Sometimes thickness of weathered rock depth through Seismic-Refraction	- Reduction of slope angle - Trimming and scaling - Slope support and restraining measures - Drainage of local springs and seepages - Erosion protection or buttress at toe
b Debris slide slab slide when debris moves and stays intact		Cohesionless strongly weathered S, M, I. Cohesionless residual and colluvial soils. Local weathering zones of bedrock aligned parallel to the slope Parameters C = O I ≤ angle of slope ϕ of failure planes if any (see factors).	Ⓐ Ⓒ	1 P 2 W 3 Often, the control of the debris failure is structural and should thus be assimilated to that of rock slides 4 U 5 Upslope runoff/ground water raising moisture content of debris in potential debris slide zones	25° - 45°	slow to rapid (debris avalanche)	1 Structural and lithological study 2 and permeability est. of rock and pot. failed of failed material 3 Brief hydro geology 4 Rock face position under pot. failed or failed mantel through Seismic-R and Resistivity	- Reduction of slope angle - Drainage - Cut-off shallow within slide zone - Erosion protection, gazoning and afforestation - Pervious buttress at toe or protection against erosion

Source: Varnes 1978, Fookes et al. 1984 and A.Wagner 1984 and 1988

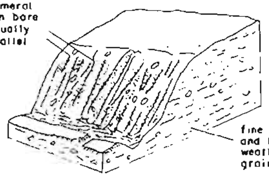
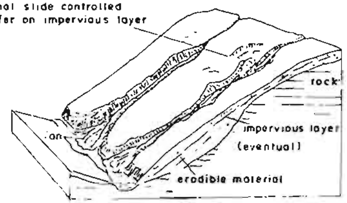
TABLE 12.3 Slides and Flows

	CHARACTERISTIC FORM	MATERIAL	MOUNTAIN ZONES	COMMON FACTORS CONTRIBUTING TO INSTABILITY OR EROSION	TYPICAL SLOPE ANGLE	COMMON RATE OF MOVEMENT	SURVEY TOPICS	CONSTRUCTION AND REMEDIAL WORKS
C. Mudslide (lobate slide) (back side shear) often promoted by freeze/thaw cycle in silty-clay soil		Fine to medium S and foliated M weakened by intense weathering in presence of groundwater Fine colluvial and residual (eluvial) soil Parameters C>0 to C >> 0 Φ rather low	(B)(C)	1 W 2 P 3 L and by other movement 4 U 5 Upslope runoff/groundwater, raising moisture content of debris in potential unstable zone	10°-30°	Very slow (mostly) to rapid	1 Soil study with an estimate 2 Brief hydrogeology 3 Rock face position and water table position in potentially failed or failed soil through seismic R and resistivity	– Drainage through french drain and underground pipes – Reduction of slope angle – Erosion protection of eroding channels within slide and of toe – Pervious butress at toe – Revegetation
Rotational variants: slump (rock), slump earthflow (soil)		Thick accumulation of soft rock, transported soil. Homogenous fine S rocks Highly to completely weathered M and I rocks. Interbedded coarse and fine silt-clay soils. Parameters C > 0 to >> 0 Φ medium to low	(B)(C) 1. P 2. U 3. L 4. W 5. EQ and blasting		15°-40°	Very slow to rapid	1 Soil (or rock study with estimate 2 Brief hydrogeology 3 Position of the perched water table and the discontinuity through resistivity and seismic-R	– Excavation of slope head – Loading of slope toe – Drainage of perched water by vertical gravity drains or horizontal pipes – Erosion protection of toe Consider realignment for large active slide
C – FLOW 1 Debris flow includes dry debris flow, mass transport events		Mainly medium-coarse highly-completely weathered rocks S, M or I (no carbonates) with abundant surface/near surface groundwater Medium-course R and transported soils (but not scree) Parameters: or rather small medium to high	(B)(C)	1 P and to raise water contents for viscous flow 2 W 3 Upslope runoff (groundwater and erosion increasing water and sediment supply, adding to flows in existing channels 4 EQ Debris heavily loaded flood may cause extensive undercut and destabilize wide valley zones	20-45° as initial angles but may run on flatter slopes	Rapid to extremely rapid	In potential failure zones: estimate of overburden, thickness, and position of water table through field survey or/and seismic-R and resistivity surveys	– Drainage in failure zone – Clearing and road maintenance – Erosion protection for furrows and eroding channels within flow
2. Mudflow variant: volcanic mud huayco (Andes) earth flow range is from slow stiff mud slides to mud floods		Mainly fine S and foliated M intensely weathered in presence of groundwater Fine C and R soils Parameters C rather high Φ low	(B)(C)	1 P and to raise water contents for viscous flow 2 W 3 Upslope runoff etc. as for debris (flow) 4 EQ	10°-30°	Slow to rapid	In potential failure zones: as above	– Drainage in failure zone – Clearing and road maintenance – Erosion protection for eroding channels within flow – Consider realignment for large active flows

Source: Varnes 1978, Fookes et al. 1984 and A. Wagner 1984 and 1988

Table 12.4

TABLE: 12.4 Wash Erosion

	CHARACTERISTIC FORM	MATERIAL	MOUNTAIN ZONES	COMMON FACTORS CONTRIBUTING TO INSTABILITY OR EROSION	TYPICAL SLOPE ANGLE	COMMON RATE OF MOVEMENT	SURVEY TOPICS	CONSTRUCTION AND REMEDIAL WORKS
A – WASH EROSION 1. Rills	small ephemeral channels on bare slopes, usually in sub-parallel network 	Highly-completely weathered fine rocks or all types of soil especially in fine sand/silt range. Homogeneous silty-clay C soils Parameters C rather high ϕ rather low	Ⓑ Ⓒ sometimes in Ⓐ frequent at head and crown of soil slope movement	1. P through direct effect of surface runoff 2. Overgrazing, vegetation clearance, excavation, and spoil disposal producing bare ground 3. W of fine S, M, I	20-50°			– Erosion protection and revegetation – Excavation trimming and regrading
2 Gullies	rotational slide controlled by aquifer on impervious layer 	R, T and C soils soft or/and completely weathered rock of all types of, excepting fine S, rocks and carbonates Parameters C low to medium ϕ rather low	Ⓐ Ⓑ Ⓒ	1 P through direct effect of surface runoff 2 Afforestation increasing water runoff 3 Alteration to side slope by fills, tips or excavation 4 Sudden lowering of main stream/river level by erosion (debris flow) 5 Mass movements up-slope concentrated in existing gullies.			General geological survey of the potentially critical area or of the failed zone Use of resistivity and seismic-R methods	– Gully erosion protection measures for channel bed. (ex: check dams) – Erosion protection and revegetation of side slope – Drainage of rotational slides if any.

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MATERIAL

- I igneous
- M metamorphic
- S sedimentary
- R residual (eluvial)
- T transported
- C colluvial

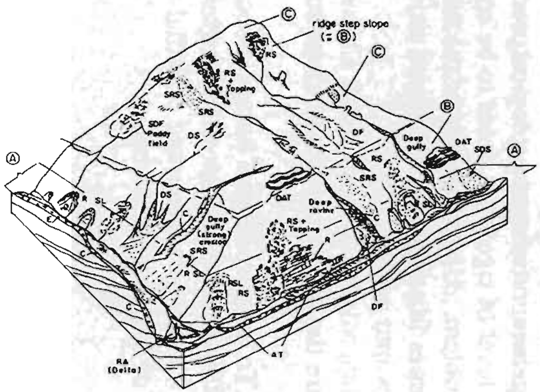
Fine, medium, coarse refers to grain size. Fine can also mean high content of silt and/or clay free or contained as components

FACTORS

- P Precipitation, raising ground-water table, increasing pore pressure on potential slip planes
- W Weathering, common to almost all processes
- U Undercutting by river action or excavation
- L Loading of slope head, usually artificial
- EQ Earthquakes shock

RATE OF MOVEMENT APPROXIMATE RANGES

- Extremely rapid (ER) – 1m/s
- Very rapid (VR) – less than 1m/s
- Rapid (R) – less than 1m/s – 1m/min
- Medium (M) – less than 1m/min to 1m/day
- Slow (S) – less than 1m/day to 1m/month
- Very Slow (VS) – less than 1m/month to 1m/year
- Extremely Slow (ES) – 1m/10 years



ⒶⒷⒸ	Mountain areas
AT	Alluvial terraces
C	Colluvim
DF	Debris flow
DS	Debris slide
E	Eluvium
OAT	Old alluvial terrace
RA	Recent alluvium
R	Rock
RS	Rock slide
RoSL	Rotational slide
SDF	Stabilized deris flow (often with paddy fields)
SDS	Stabilized debris slide
SRC	Stabilized rock-slide
SRS	Stabilized rotational slide

Source: Varnes 1978, Fookes et al. 1984 and A. Wagner 1984 and 1988