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1. Learning outcomes

After studying this module, you shall be able to:

- Know different causes of mass wasting and mass movements.
- Learn about mode of earth and rock mass failures and types of landslides.
- Relate and quantify rock mass properties to identify vulnerability of slopes and magnitude of the problem.
- Suggest different civil engineering solutions to mitigate problems of landslide.

2. Introduction

The earth is a dynamic system and is the only planet which supports life. Human beings are one of the millions of species thriving presently on the earth and are in constant interaction with their surroundings, the environment. The present environment has evolved during geological past through constant interaction amongst barysphere, asthenosphere, lithosphere, hydrosphere, biosphere and atmosphere. These multi sphere earth systems operates uniformly and relentlessly, but at times, are punctuated by sudden and violent events posing threat to its inhabitants including human beings. The dynamics of the earth's interior is fueled by its internal heat resulting into generation of endogenous forces which drives large continents, builds mountains, produces volcanic eruptions and triggers earthquakes. At its exterior it is the solar heat which generates exogenous forces instrumental in driving various processes at the earth surface, related to glacier, river, wind and sea systems. Both endogenous and exogenous forces are operating since the inception of the earth and will continue to operate in future, constantly changing physical, chemical and biological face of the earth and shall bring human beings to their toes by their sudden and swift action causing harm to them, their economic and social institutions. These surprising actions are called as natural disasters.

There are many natural and manmade disasters which inflict losses to human beings and their socio-economic gains. The important natural hazards are drought, flood, cyclone, landslides, volcanism, earthquakes, tsunami and bolides impact. These events are part and parcel of earth's dynamics and cannot be prevented from occurring. But, their impact can be minimized by reducing its severity, frequency and possibly its area of recurrence. This entails awareness, preparedness and mitigation, based on detailed analysis of its genesis, its past occurrences, probability of future events in terms of recurrence and magnitude.

India is vulnerable to a large number of natural disasters because of its typical geography and geological setup. 68% of the cultivable area is vulnerable to drought; over 12% of land is prone to floods and river erosion. 58.6% of the landmass is prone to earthquakes of moderate to very high intensity and of the 7,516 km long coastline, close to 5700 km is prone to cyclones and tsunamis. Hilly areas of Jammu and Kashmir, Himachal Pradesh, North Eastern States, parts of Maharashtra, Karnataka, and Kerala etc. are at risk from landslides and avalanches.

Large scale mass movements are common scene in Himalayan mountain system causing immense loss of life and economy. This high susceptibility is due to active tectonics, high seismicity, steep slopes, complex geological setting, heavy snow and rain fall. Landslide events are also reported from Deccan Plateau, Western Ghats and Nilgiri hill regions especially during rainy seasons. Many of these landslides have anthropogenic causes as they take place along road and rail network (Konkan Railways). As compared to above mentioned regions, rocks of Aravalli and Vindhyan Hill ranges have lesser incidence of landslides perhaps due to the fact that these areas have lesser amount of rainfall and rocks are comparatively less weathered. In recent years some major incidents of flash floods accompanied with large scale landslides have been observed in last five years or so in Ladakh, Uttarakhand, Maharashtra and Arunachal Pradesh.

Proper understanding of landslide phenomenon, controlled and planned, development of landslide prone areas and pertinent civil engineering measures can reduce the occurrence of landslides and minimize the losses.

3. Landslide

Nearly all exposed rocks and soils are subjected to weathering and erosion by natural processes termed as mass wasting. The constant but slow, down slope movement under the influence of gravity of disintegrated, degraded rocks, rock debris and resultant soil on slopes is termed as mass movement. When after a long period of lull and dead slow movement, there is a sudden transport of large amount of material then it is termed as landslide. As such it is a part of natural system and process, perhaps the first step in making of soil, which is the base of all kind of vegetation, specially agriculture. At the same time, it is a dreaded natural hazard, may cause loss of natural resources, infrastructure, property and life if there is improper development in landslide hazard prone areas (Fig. 1).

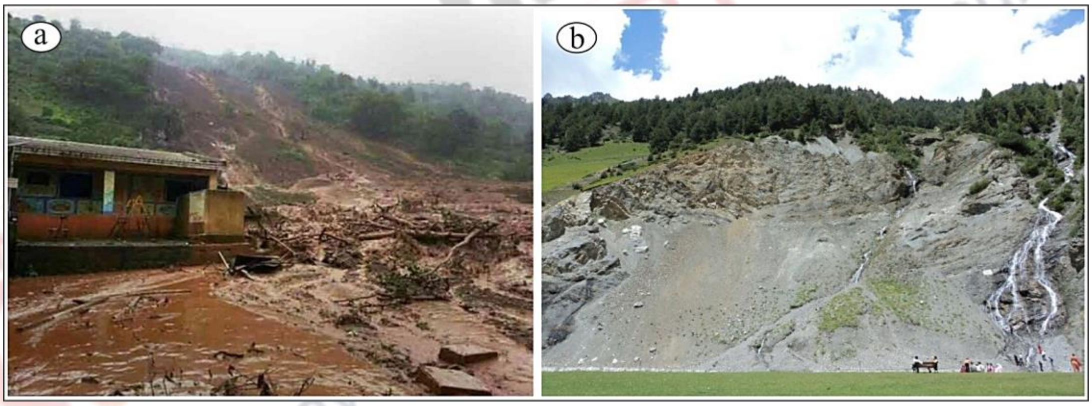

Fig. 1 Landslides in (a) Malin Pune (30-7-2014), (b) Sonmarg, J & K (15-06-2010).

3.1 Causes of Landslides

Landslide occurs when ever downward pull of gravity or shearing stresses overcome the static and resisting forces of the natural earth materials. Gravity is the main driving force for creating landslide movements followed by ingress of water. In general, the causes can be classed into natural and anthropogenic.

3.1.1 ***Natural Causes:*** Following are the important natural causes responsible for landsliding:

a) All slopes undergo degradation due to weathering and downslope movement of material. If the angle of slope is greater than the angle of repose, then this process is continuous. But when it fails after a long static period or spasmodically then it becomes a landslide. The nature of slide may vary from the pure earth failure to rock failure to complex slides.

b) The presence of weak planes in form of bedding, joints and shear zones inclined towards the slope create potential slip surface along which landslide may take place.

c) The presence of salts, clay and altered mafic rocks either dissolved, leached or washed by the ingress of water can create weak planes for slope failures.

d) Pore water pressure in weathered rocks, joint water pressure in rocks due to presence of ground water or water seeped due to incessant rain may result into reduction in resistance to shear and also make clays a lubricant to cause landslide.

e) Toe erosion or under cutting caused by river, glacier, sea wave and even wind may make a slope unstable leading to its failure.

f) Wetting and drying as well as freezing and thawing may result into weakening of slope mass leading to sliding.

g) Earthquakes and volcanism can also trigger an event of landslide alone as well as in combination.

3.1.2 ***Anthropogenic Causes:*** At many instances it is the anthropogenic activities in hilly areas have resulted into slope failures such as:

a) Improper construction of houses and buildings.

b) Excavation and cutting of slope for making roads, rail tracks and other infrastructures.

c) Indiscriminate mining, associated blasting and vibrations caused by heavy machinery.

d) Deforestation and agricultural activity.

3.2 Classification and Terminologies

Landslide is a general term and includes many different kind of mass movement. It can be classified on the basis of material involved and type of movement in following types (Table 1).

Table 1: Classification of Land-Slope Processes and Mass Movement

Type of Movement	Material Involved			
	Rock	**Soil**	**Mixed (Debris)**	**Any Other**
Topple	Rock Topple	Slump	Debris Topple	Ice Block Topple
Fall	Rock Fall	Slump	Debris Slump	Ice Block Fall
Slide	Rock Slide *Planar / Wedge*	Earth Slide *Translational / Rotational*	Debris Slide *Translational / Rotational*	Ice Block Slide
Spread	-	Earth Spread *Wet / Dry*	Debris Spread *Wet / Dry*	Snow Spread *Avalanche / Solliflucti on*
Flow	-	Earth Flow *Saturated*	Debris Flow *Saturated*	Mud Flow Volcanic Ash Flow *Saturated*
Complex	Combination of any of the above	Combination of any of the above	Combination of any of the above	Combination of any of the above

3.2.1 ***Slump***: More commonly found in soil wherein down slope movement is characterized by rotational failure surfaces. It is a common type of landslide in areas of intensely weathered rocks or on soil rich slopes. Different elements of such slides are given in figure 2.

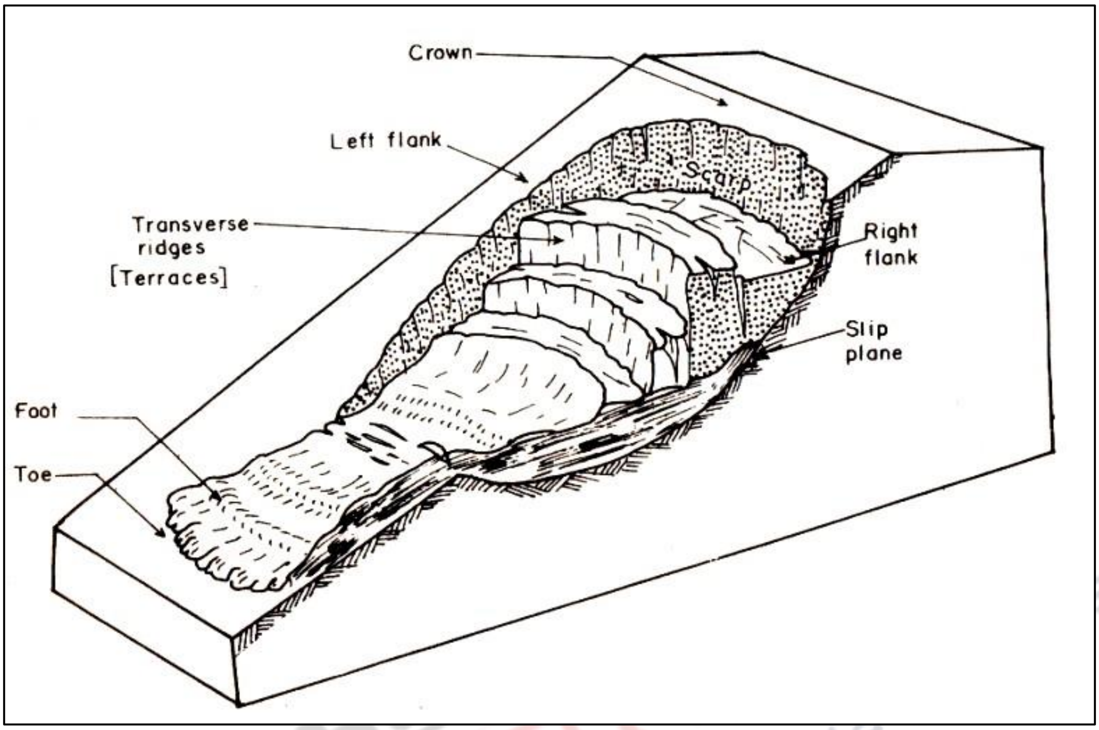

Fig. 2 Schematic diagram of a landslide in homogenous unconsolidated medium with curvy-planar failure surface. See different parts of a landslide.

3.2.2 ***Rock Fall and Topple***: It is free falling action of rocks wherein it is not in contact with the ground usually termed as *rock fall* (Fig. 3a). It is a common phenomenon on vertical slopes and rock cliffs which are subjected to under cutting either by glacier, river or sea waves. When the angle of slope is very high and rocks are dislodged along very high angle slope then it is called as *toppling failure* (Fig. 3b).

3.2.3 ***Rock Slide*****:** In this case rocks slides along planar weak surfaces or joints which are dipping towards the slope. The rock slides are very common in rocky areas especially when joints are filled with clay which on becoming saturated with water act as lubricant and aggravate this process of land sliding. The rockslide may be in form of planar or wedge slide (Fig. 3c & d)**.**

3.2.4 ***Debris Slide*****:** Sometimes weathered rock material comprising rocks and soil mix are subjected to sliding are usually along rotational single or multiple failure surfaces. Such kind of slides are also termed as complex landslides.

3.2.5 ***Flows*****:** Involves comparatively fast and consistent movement of very fined grained material saturated or over saturated with water. It is termed as *earth flows* and *mudflows* depending up on the involvement of non-cohesive and cohesive soil respectively. Fast moving volcanic ash saturated with water is called as *ash flows*, in case it is hot and incandescent then *nuee ardente* or *lahars*.

3.2.6 ***Avalanches*****:** Fast moving snow along steep slopes is termed as *snow avalanche*, a common phenomenon in areas with permanent snow and regions of heavy snow fall. Snow avalanches can be triggered by earthquake, rain, sudden vibrations due to blasting or flying aircrafts apart from human interventions.

3.2.7 ***Creep*****:** Extremely slow movement cannot be seen but can be observed indirectly. Usually recognized by presence of trees with curved stems, tilted monuments, distorted fences and bends in lower part of telephone or electric poles on the creeping slopes.

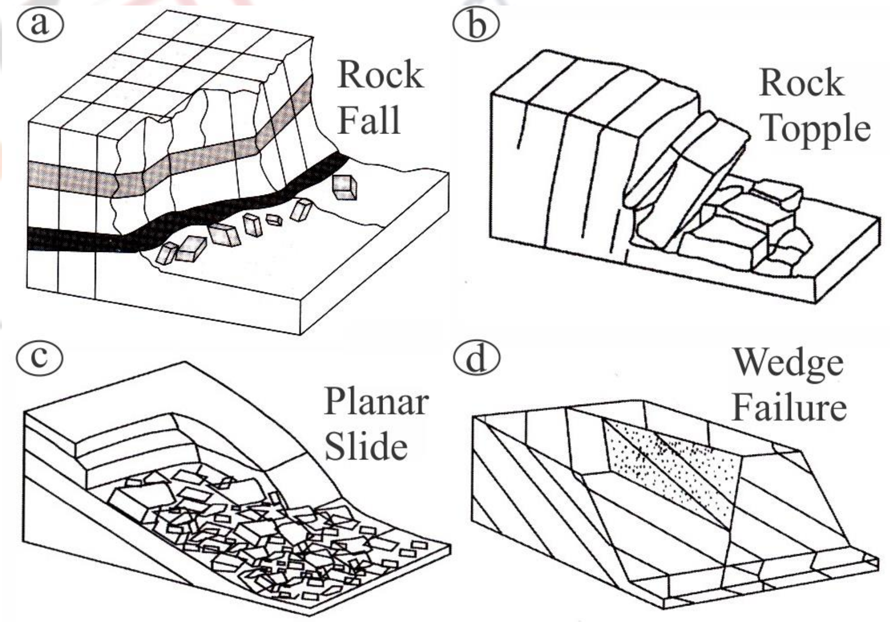

Fig. 3 Types of landslide on rocky slopes. (a) Rock fall on vertical slope and closely spaced joints, (b) Toppling failure on high angle slope with prominent vertical joints, (c) Planar rock slides along joint/bedding plane with low angle dip, (d) Rocks showing wedge failure, common on slopes with conjugate joint sets.

3.2.8 ***Solifluction:*** In the periglacial regions where freeze and thaw is common saturated soil or rock debris in active layer may fail at slopes less than even 5^0 inclinations.

3.2.9 ***Caving:*** A common problem where limestones are present. The seeping waters dissolve the rock and make it cavernous. When the dimensions of the caves become large the roof collapses causing subsidence of overlying structures.

3.3 Landslide Hazard Zonation

Landslide hazard zonation (LHZ) map is an important method to identify vulnerability of a slope or its parts. It is based on different ground characters and causative factors influencing stability of slopes. It is a tool which helps in tackling the menace of land sliding in following ways:

a) It helps the planners and engineers to identify hazard prone areas and to choose proper site or place for the infrastructure development.

b) It helps in taking precautionary measures to avoid syn-construction problems in hilly terrains and to undertake proper mitigation techniques to arrest or minimize further deterioration.

c) In case of road and rail networks in the hilly terrains landslides are major problems. Slope failure vulnerability can identify different locations where precautions can be taken.

d) It helps in identifying the most vulnerable areas so that Proper LHZ maps around the dam and reservoir site will help in controlling slope failures in reservoir area to control siltation and over spilling of water.

e) Transportation and water pressure tunnels can be realigned to avoid known and vulnerable landslide areas, especially at their mouth or portals.

The LHZ maps are made by incorporating different factors by mapping them, involved in the process of mass wasting and movement. These maps can be synthesized by using GIS technique to identify most and least vulnerable areas. These maps can be made on the scales of 1: 50,000 for regional scale, 1: 25,000 to 1: 50,000 for macro scale and 1: 2,000 to 1: 10,000 for micro scale zonation. The suitability of map scale will depend upon the size of the project. The Important factors to be mapped include: (i) Lithology, (ii) Topography and Slope Morphometric Analysis, (iii) Structural Geology, (iv) Surface Hydrology, (v) Forest Cover and Vegetation, (vi) Anthropogenic Land Use, (vii) Groundwater Condition.

Collation and comparison of these factors can help in identifying the susceptibility of a slope to failure. There are various methods which can be employed for this purpose. Two indigenous methods, one developed by Central Building Research Institute (CBRI), Roorkee and other developed by Bureau of Indian Standard (BIS) in collaboration with Geological Survey of India (GSI) as IS: 14496 Part I and II-2004 are briefly discussed here. Another method termed as Slope Mass Rating by Romana (1995) is discussed after wards.

3.3.1 *Landslide Susceptibility Score (LSS)*

It was developed by the CBRI, Roorkee and is based on identification of different factors and their categories. Each factor is given ranks as per their importance and their categories have been given weightage as given in Table 2. The LSS is being calculated using formula:

$$LSS = \sum (Rank \times Weight)$$

If LSS is greater than 300, susceptibility class is high, LSS from 300 to 200 is for moderate susceptibility and LSS less than 200 is for low susceptibility. The higher value slopes are more vulnerable to landslide as compared to low score ones.

Table 2: Ranks and weightage for the factors and their categories for calculating Landslide Susceptibility Scores

Factors	Rank	Category	Weight
Hydrology	9	Flowing	9
		Wet	6
		Dry	1
Slope	8	Flat	0
		0 - < 15°	2
		15 – 30 °	5
		30 – 45 °	7
		> 45 °	9
Overburden Thickness	7	< 1	1
		1 – 2m	3
		2 – 3m	6
		> 3m	9
Slope and Discontinuity Relation	6	Dip Slope	9
		Oblique Slope	5
		Opposite Slope	1
		Flat Slope	0
Joint and Fractures	5	High	9
		Moderate	4
		Low	2
Weathering	4	High	6
		Moderate	5
		Low	2
Rock mass	3	Soil and Boulder	9
		Thinly Bedded	6
		Thick Bedded	3
		Massive	1
Lithology	2	Schist / Shale*	7
		Sandstone* / Limestone*	6
		Gneiss / Quartzite*	5
		Basalt* / Rhyolite*	4
		Granite* / Granulite*	3
Vegetation Type	1	Barren	9
		Sparse	7
		Moderate	5
		Agriculture	3
		Thick	1
* Added by the author to make it broad based and realistic			

3.4 Landslide Hazard Zonation/Evaluation

The BIS has given a code for landslide hazard mapping based on ten causative factors with each factor given landslide hazard evaluation factor (LHEF) as 1 or 2, totaling 14 (Table 3). The area to be mapped for landslide hazard zonation is to be divided into different smaller regions using maps of 1: 50,000 to 1: 25,000 for macro zonation and 1: 10,000 to 1: 5,000 for micro zonation.

Table 3: Causative factor and Landslide Hazard Evaluation Factor as per IS: 14496 Part II

S.No.	Causative Factors	LHEF
1	Lithology	2
2	Structure	2
3	Slope Morphology	2
4	Relative Relief	1
5	Land Use	1
6	Land Cover	1
7	Hydrological Conditions	1
8	Rain Fall	1
9	Landslide Incidence	2
10	Slope Erosion	1
Total		14

Depending upon the estimated value of each region the entire area can be identified in to five hazard zones as per the Table 4.

Table 4: Landslide zones for total estimated hazard as per IS: 14496 Part II

Total Estimated Hazard as per IS 14496 Part II	Zone Category	Zone Description
<4.90	I	Very Low Hazard
4.91 – 7.00	II	Low Hazard
7.10 – 8.40	III	Moderate Hazard
8.41 – 10.50	IV	High Hazard
> 10.50	V	Very High Hazard

3.5 Preparedness, Mitigation and Civil Engineering Interventions

There are three kinds of regions people live in. The plain areas characterized by very low angle slopes to flat tracts, mountainous areas with high angle slopes, mostly in valleys or valley flanks and areas at the juncture of mountains and plains where ground with different slope angles are encountered. Barring first kind rest two regions are prone to different kind of landslide occurrences. The problem of landslides is as such cannot be avoided as it is a natural phenomenon on hill slopes. But, the problem with inhabitants of hilly and mountainous areas is that they have to make their houses and related buildings on these slopes and with increasing population and limited safe habitable area they knowingly or unknowingly go for unsafe slopes or places. For people living in such inhospitable areas government has to provide roads, rail tracks, hospitals schools and other infrastructure which too need safe ground. The role of civil engineers of different organizations are of utmost importance as they have to provide safe lifeline buildings and infrastructure apart from guiding people for making safe buildings in terms of suitable location and proper construction technology.

The very first step to counter landslide is the identification of areas prone to landslide and making landslide hazard zonation maps. This can be achieved by taking into account palaeo landslide scars, geomorphology, meteorology, groundwater, weathering state of the rocks, natural vegetation and land use pattern of the region. Depending up on the slope angle, weathering state of rocks, rock types, presence of deformation structures and its orientation with respect to slope, past and recent past occurrences of rock fall and slide etc. will be the deciding factor for development of residential, civil utility structures and infrastructure.

The problem of rock fall, the most common on natural and manmade slopes are tackled by forming rock trap ditches, rock catching nets, rock shelters, wire meshing and chain link fencing. The method to be employed will depend upon the average size of the falling material and probability of fall events, which in turn are function of weathering state of rock mass, number of joints per unit area and verticality of slope. Monitoring of landslide prone area at various spatial scales is an important step as for as prevention and preparedness are concerned. This includes ground surveying at fixed reference points, measurements of rock displacement and crack widening using glued studs and inclinometers in boreholes to monitor any movement. On the basis of landslide zoning map different options can be employed such as slope modification by excavation and filling, reducing pore water pressure and weight of the rock mass by dewatering and by improving drainage. Vegetation turfing and afforestation of slopes to provide root matting which increases tensile strength of soil while deep roots to provide anchorage. Installation of gabion wall, construction of concrete buttresses, retaining wall, dental masonry and concrete spray to provide mass support to slopes (Fig. 4).

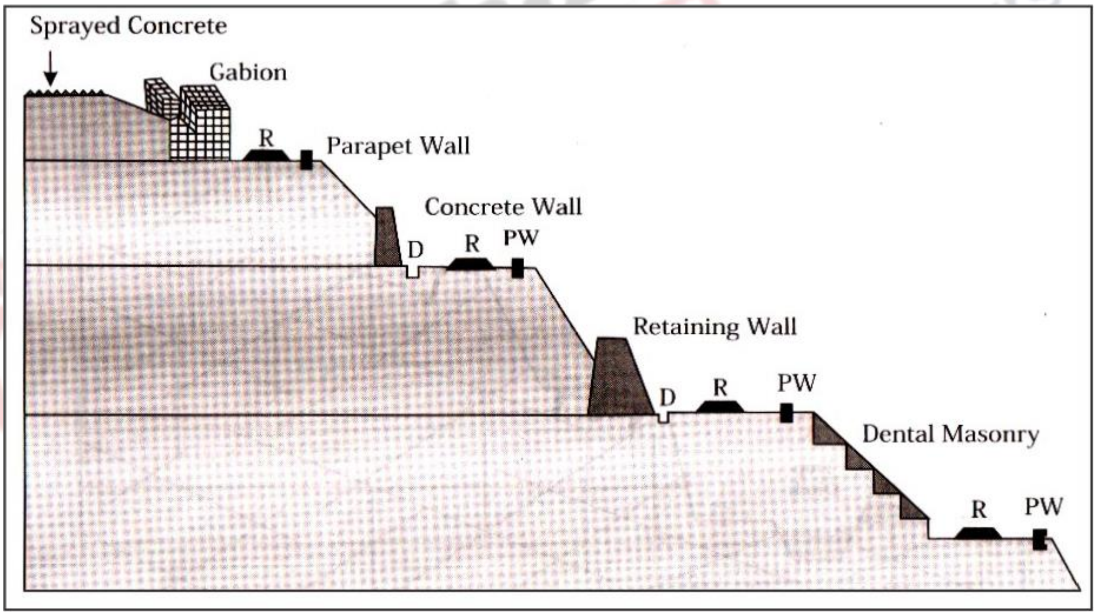

Fig. 4 Different mass support for controlling landslides to protect a road. R- Road, D- Toe Ditch, PW- Parapet wall

Ground anchors in form of grouted dowels, rock bolts, bored piles and rock anchors provide tensile strength and oppose forces causing landslides (Fig. 5).

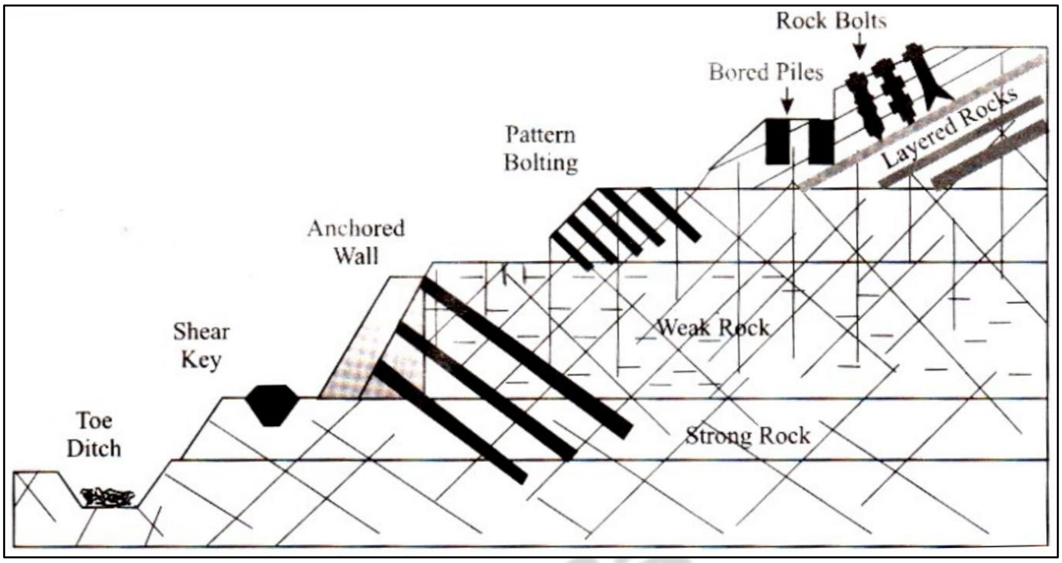

Fig. 5 Different kinds of ground support to stabilize the ground.

Under cutting or lateral scouring by river or sea waves called as toe erosion may lead to landslides, can be controlled by erecting gabion walls, laying rip rap or tripods. Many other specific options can be used, especially to keep road/rail tracks safe from rock fall (Fig. 6).

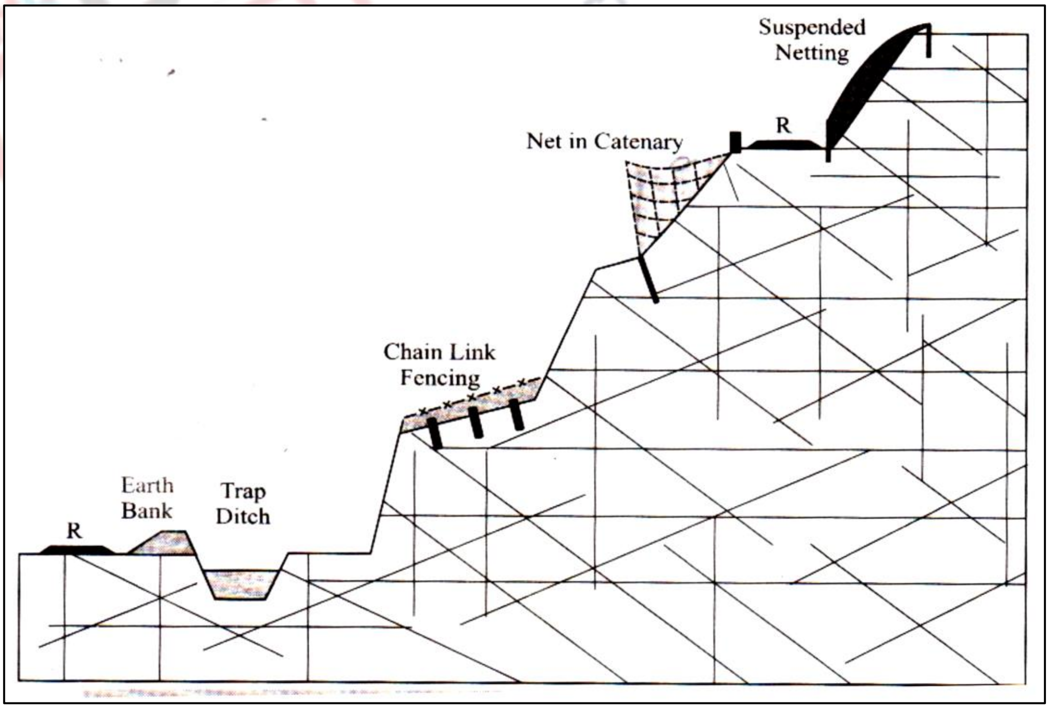

Fig. 6 Some other methods for mitigating the problem of rock fall to save a road/rail track.

3.6 Slope Mass Rating

Romana (1985) extended the RMR system for quantifying rocky slopes and to devised support system for slope stabilization. He defined different ***slope factors*** based upon disposition of joints (discontinuity) with respect to angle and orientation of slopes. Accordingly, different favorability classes are identified with rating values (Table 5) to be used in formula:

$$SMR = RMR_{Basic} + (F_1 \times F_2 \times F_3) + F_4$$

F_1- Defines parallelism between strike of most critical joints (α_j) and orientation of slope face (α_S).

F_2- Defines the dip of the joint (β_j). It has same rating values for planar (P) and wedge (W) failure while different for toppling (T) failure.

F_3- Defines relationship between the inclination of slope face and the dip of joint.

F_4- Termed as adjustment factor, takes into account method of excavation (Table 6).

Table 5: Rating values for different Slope Factors (Romana, 1985).

Case of Slope Failure		Very Favorable	Favorable	Fair	Unfavorable	Very Unfavorable
P T W	$\|\alpha_j - \alpha_s\|$ $\|\alpha_j - \alpha_s - 180^0\|$ $\|\alpha_j - \alpha_s\|$	> 30^0	30^0 - 20^0	20^0 - 10^0	10^0 - 5^0	< 5^0
P/W/T	**F_1**	0.15	0.40	0.70	0.85	1.0
P W	$\|\beta_j\|$ $\|\beta_j\|$	< 20^0	30^0 – 20^0	35^0 - 30^0	45^0 - 35^0	>45^0
P/W	**F_2**	0.15	0.40	0.70	0.85	1.0
T	**F_2**	1.0	1.0	1.0	1.0	1.0
P W	$\|\beta_j - \beta_s\|$ $\|\beta_j - \beta_s\|$	> 10^0	10^0 - 0^0	0^0	0^0 – (- 10^0)	< - 10^0
T	$\|\beta_j + \beta_s\|$	< 110^0	110^0 - 120^0	> 120^0	----	----
P/W/T	**F_3**	0	- 6	- 25	- 50	- 60

Table 6: Values of Adjustment factor for method of excavation.

Method of Excavation	**F_4 Values**	**Method of Excavation**	**F_4 Values**
Natural Slope	+15	Pre Splitting	+10
Smooth Blasting	+8	Normal Blasting	0
Mechanized Excavation	0	Poor blasting	-8

As per the SMR values Romana (1985) defined five slope stability classes shown in Table 7, which can be used for landslide zonation, cut slope design, and in deciding slope for open cast mines.

Table 7: Slope Stability Classes based on SMR Values.

Class No.	**V**	**VI**	**III**	**II**	**I**
SMR Values	0 – 20	21 – 40	41 – 60	61 – 80	81 – 100
Rock Mass Description	Very Bad	Bad	Normal	Good	Very Good
Stability	Completely Stable	Unstable	Partially stable	Stable	Completely stable
Failures	Big planar or soil like complex failure	Planar or big wedges	Planar along joints and wedge failure	Some block to toppling failure	No Failure
Failure Probability	0.9	0.6	0.4	0.2	0

Broad remedial measures can also be suggested by detailed study of the problem, analysis of SMR values and good engineering acumen as per the Table 8.

Table 8: SMR Classes and suggested remedial measures.

SMR Classes	**SMR Values**	**Remedial Measures**
Ia	91 – 100	None
Ib	81 – 90	None to some scaling
IIa	71 – 80	Scaling, provision of toe ditch or fence net
IIb	61 – 70	Toe ditch or fence net, Spot to pattern bolting
IIIa	51 – 60	Toe ditch or fence net, Pattern bolting and Spot shotcreting
IIIb	41 – 50	Toe ditch and wall, Pattern bolting, Systematic shotcreting, Dental concrete
IVa	31 – 40	Anchors, Systematic shotcreting, Dental concrete, Drainage Improvement
IVb	21 – 30	Systematic reinforced shotcrete, Concrete wall, Re-excavation, Deep drainage
V	11 – 21	Re-excavation, Deep drainage, Gravity Wall, Anchored retaining wall with buttresses

The Indian Scene: Large scale mass movements are common scene in Himalayan mountain system causing immense loss of life and economy. This high susceptibility is due to active tectonics, high seismicity, steep slopes, complex geological setting, heavy snow and rain fall. Specially with the beginning of monsoon numerous cases of landslides are being reported from Sikkim, Tripura, Meghalaya, Nagaland, Arunachal Pradesh, Assam and hilly tracts of West Bengal apart from J&K, Uttarakhand and Himachal Pradesh. Landslide events are also reported from Western Ghats, Deccan Plateau and Nilgiri hill regions especially during rainy seasons. Many of these landslides have anthropogenic causes as they take place along road and rail network (*Konkan Railways*). As compared to above mentioned regions rocks of Aravalli and Vindhyan Hill ranges have lesser incidence of landslides, perhaps due to the fact that these areas have lesser amount of rain fall and rocks are comparatively less weathered.

Some recent events of landslides in India are as follows:

a) July 11-12, 1996: Massive landslide in Jaldhaka Valley and Kalimpong hills.

b) June 9, 1997: Hill slope failure and devastation in Gangtok.

c) August 18, 1998: landslide leading to death of 220 people at Malpa, Uttarakhand.

d) July 9, 1999: Landslide in Kurseong town, West Bengal.

e) July 12, 2000: Mumbai Landslides killing 67 people.

f) September 24, 2003: Varunavat Landslide, Uttarakhand affected 3000 people.

g) October 8, 2005: More than 2400 landslide events widely spread in J&K in the aftermath of Muzaffarabad Earthquake.

h) August 14-15, 2007: Catastrophic landslides killing more than 62 people in Dhara Village of Himachal Pradesh.

i) June 13-15, 2013: Kedarnath Landslides, Uttarakhand in the aftermath of cloud bursts caused more than 5700 death and loss of property.

j) July 30, 2014: Malin Landslide near Pune destroying the whole village after heavy downpour.

k) September, 14-15, 2014: Cloud burst, flashfloods and landslide in Srinagar, J&K.

l) 2016: Tawang Landslide, Arunachal Pradesh killing 16 people.

The landslide is a natural phenomenon and is happening from the remotest past of geological times and is the very first step in the formation of one of the most needed natural resource for human beings i.e. soil. Without soil and thereby agricultural activity, human civilization cannot thrive on this earth. Hence we cannot blame this process of landslide. It is the folly of human beings whose reckless activities near the slopes has made this very natural process a hazard.

3.7 Summary

The earth is one of the most dynamic planet supporting different kinds of life including human beings who are in constant interaction with their surroundings, the environment. The processes which act on the earth constantly change its face. Sometimes sudden and swift action of nature cause harm to economic and social institutions of human beings. These surprising actions are called as natural disasters. There are many natural hazards which can inflict losses to human beings and their socio-economic gains. The important natural hazards are *drought*, *flood*, *cyclone*, *landslides*, *volcanism*, *earthquakes*, *tsunami* and *bolides impact*. These events are part and parcel of earth’s dynamics and cannot be prevented from occurring. But, their impact can be minimized by reducing its severity, frequency and possibly its area of recurrence. This entails awareness, preparedness and mitigation, based on detailed analysis of its genesis, its past occurrences, probability of future events in terms of recurrence and magnitude.

Nearly all exposed rocks and soils are subjected to weathering and erosion by natural processes termed as mass wasting. The constant but slow, down slope movement under the influence of gravity of disintegrated, degraded rocks, rock debris and resultant soil on slopes is termed as mass movement. When after a long period of lull and dead slow movement, there is a sudden transport of large amount of material then it is termed as landslide. As such it is a part of natural system and process, perhaps the first step in making of soil, which is the base of all kind of vegetation, especially agriculture. At the same time, it is a dreaded natural hazard, may cause loss of natural resources, infrastructure, property and life if there is improper development in landslide hazard prone areas

Landslide occurs when ever downward pull of gravity or shearing stresses overcome the static and resisting forces of the natural earth materials. Gravity is the main driving force for creating landslide movements followed by ingress of water. In general, the causes can be classed into natural and anthropogenic. The important natural causes responsible for land sliding are:

a) Degradation of slope due to weathering and erosion.

b) Downslope movement of material on slopes with angle greater than the angle of repose.

c) The presence of weak planes in form of bedding, joints and shear zones inclined towards the slope create potential slip surface causing landslide.

d) The presence of salts, clay and altered mafic rocks either dissolved, leached or washed by the ingress of water can create weak planes for slope failures.

e) Pore water pressure in soil and weathered rocks as well as joint water pressure in rocks due to presence of ground water or water seeped due to incessant rain resulting into reduction in resistance to shear leading to landslide.

f) Toe erosion or under cutting caused by river, glacier, sea wave and even wind may make a slope unstable leading to its failure.

g) Wetting and drying as well as freezing and thawing may result into weakening of slope mass leading to sliding.

h) Earthquakes and volcanism can also trigger an event of landslide alone as well as in combination.

At many instances it is the anthropogenic activities in hilly areas have resulted into slope failures such as:

a) Improper construction of houses and buildings.

b) Excavation and cutting of slope for making roads, rail tracks and other infrastructures.

c) Indiscriminate mining, associated blasting and vibrations caused by heavy machinery.

d) Deforestation and agricultural activity.

Landslide is a general term and includes many different kind of mass movement. It can be classified on the basis of material involved and type of movement as:

a) *Slump:* where down slope movement of soil is characterized by rotational failure surfaces.

b) *Rock Fall:* when free falling rocks not in contact with the ground usually topple down either due to cutting either by glacier, river or sea waves or by overhanging slopes.

c) *Rock Slide:* when rocks slides along planar weak surfaces or joints which are dipping towards the slope either as planar or wedge slide.

d) *Flows*: involve comparatively fast and consistent movement of very fined grained material saturated or over saturated with water as earth flows and mudflows.

e) Fast moving volcanic ash saturated with water is called as ash flows, in case it is hot and incandescent then nuee ardente or lahars.

f) Fast moving snow along steep slopes termed as *snow avalanche* is a common phenomenon in areas with permanent snow and regions of heavy snow fall.

g) Extremely slow movement observed indirectly is termed as creep. Usually recognized by presence of trees with curved stems, tilted monuments, distorted fences and bends in lower part of telephone or electric poles on the creeping slopes.

h) Some special kind of movement is *Solifluction*. In the periglacial regions where freeze and thaw is common saturated soil or rock debris in active layer may fail at slopes less than even 5^0 inclination. Caving is another problem for regions with limestone terrain where seeping water dissolve the rock and make it cavernous. When the dimensions of the caves become large the roof collapses causing subsidence of overlying structures.

Landslide hazard zonation (LHZ) map is an important method to identify vulnerability of a slope or its parts. It is based on different ground characters and causative factors influencing stability of slopes. It is a tool which helps in tackling the menace of land sliding by identifying hazard prone areas and to choose proper site or place for the infrastructure development. It helps in ensuring measures to avoid construction problems in hilly terrains such as mitigating landslides along the road and rail networks in the hilly terrains. Land slide hazard zonation is very important around the dam and reservoir site to control slope failures in reservoir area for minimizing siltation and over spilling of water. The LHZ maps are made by incorporating different factors by mapping them, involved in the process of mass wasting and movement. These maps can be synthesized by using GIS technique to identify most and least vulnerable areas at different scales. The suitability of map scale will depend upon the size of the project. The Important factors to be mapped include: (i) Lithology, (ii) Topography and Slope Morphometric Analysis, (iii) Structural Geology, (iv) Surface Hydrology, (v) Forest Cover and Vegetation, (vi) Anthropogenic Land Use, (vii) Groundwater Condition.

Collation and comparison of these factors can help in identifying the susceptibility of a slope to failure by using LSS scores or by using IS code 14496 Part I & II. Another method termed as Slope Mass Rating by Romana (1995) can be used for designing remedial measures.

The problem of landslides is as such cannot be avoided as it is a natural phenomenon on hill slopes. For people living in such inhospitable areas the civil engineers and geologists have to play pivotal role to provide safe infrastructure apart from guiding people for making safe buildings in terms of suitable location and proper construction technology. The very first step to counter landslide is the identification of areas prone to landslide and making landslide hazard zonation maps. Depending up on the slope angle, weathering state of rocks, rock types, presence of deformation structures and its orientation with respect to slope, past and recent past occurrences of rock fall and slide etc. will be the deciding factor for development of residential, civil utility structures and infrastructure.

The problem of rock fall, the most common on natural and manmade slopes are tackled by forming rock trap ditches, rock catching nets, rock shelters, wire meshing and chain link fencing. The method to be employed will depend upon the average size of the falling material and probability of fall events, which in turn are function of weathering state of rock mass, number of joints per unit area and verticality of slope. Monitoring of landslide prone area at various spatial scales is an important step as for as prevention and preparedness are concerned. This includes ground surveying at fixed reference points, measurements of rock displacement and crack widening using glued studs and inclinometers in boreholes to monitor any movement. On the basis of landslide zoning map different options can be employed such as slope modification by excavation and filling, reducing pore water pressure and weight of the rock mass by dewatering and by improving drainage. Vegetation turfing and afforestation of slopes to provide root matting which increases tensile strength of soil while deep roots to provide anchorage. Installation of gabion wall, construction of concrete buttresses, retaining wall, dental masonry and concrete spray to provide mass support to slopes. Under cutting or lateral scouring by river or sea waves called as toe erosion may lead to landslides, can be controlled by erecting gabion walls, laying rip rap or tripods. Many other specific options can be used, especially to keep road/rail tracks safe from rock fall.

In India states in the lap of Himalayas are most vulnerable due to its young and fragile nature apart from being cradle of active tectonics, high seismicity and complex geological setting. Landslide events are also reported from Western Ghats, Deccan Plateau and Nilgiri hill regions especially during rainy seasons. Many of these landslides are human induced who have made its habitation over the slopes and have also made road and rail network without giving due thought to the slope dynamics.

Frequently Asked Questions-

Q1. Give an account of different causes of landslides?

Nearly all exposed rocks and soils are subjected to weathering and erosion by natural processes termed as mass wasting. The constant but slow, down slope movement under the influence of gravity of disintegrated, degraded rocks, rock debris and resultant soil on slopes is termed as mass movement. When after a long period of lull or very slow movement, a sudden displacement of large amount of material takes place, then it is termed as landslide. Landslide in populated area can cause loss of natural resources, infrastructure, property and life. The landslide can bring topographical changes and sometimes cause natural damming of rivers leading to flash floods.

The causes of landslides can be natural or anthropogenic. The natural causes are high angle slope, thick weathered mantle, weak and heavily jointed rocks. High or prolonged incessant rainfall more often trigger landslides by making slope heavier and lubricating the weak zones. The rise in groundwater level and high pore-water pressure are also important in abating landslides.

Destabilization of slopes by anthropogenic activities such as making houses and other infrastructural facilities such as road and rail network, mining and blasting, mine waste dumping etc. are also major causes of landslides. Deforestation and agricultural activity by human beings in hilly areas have also aggravated the problem of landslides.

Q2. Give a brief classification of landslides?

Landslide is a general term and includes many different kind of mass movement. It can be classified on the basis of material involved and type of movement in following types:

Slump**:** More commonly found in soil wherein down slope movement is characterized by rotational failure surfaces. It is a common type of landslide in areas of intensely weathered rocks or on soil rich slopes.

Rock Fall**:** It is free falling action of rocks wherein it is not in contact with the ground usually termed as *toppling failure*. It is a common phenomenon on vertical slopes and rock cliffs which are subjected to under cutting either by glacier, river or sea waves.

Rock Slide**:** In this case rocks slides along planar weak surfaces or joints which are dipping towards the slope. The rock slides are very common in rocky areas especially when joints are filled with clay which on becoming saturated with water act as lubricant and aggravate this process of land sliding. The rock slides mostly along translational failure planes may be in form of planar or wedge slide.

Debris Slide**:** Sometimes weathered rock mantle comprising rocks and soil mix are subjected to sliding are usually along rotational single or multiple failure surfaces. Such kind of slides are also termed as complex landslides.

Flows**:** Involves comparatively fast and consistent movement of very fined grained material saturated or over saturated with water. It is termed as *earth flows* and *mudflows* depending up on the involvement of non-cohesive and cohesive soil respectively. Fast moving volcanic ash saturated with water is called as *ash flows*, in case it is hot and incandescent then *nuee ardente* or *lahars*.

Avalanches: Fast moving snow along steep slopes is termed as *snow avalanche*, a common phenomenon in areas with permanent snow and regions of heavy snow fall. Snow avalanches can be triggered by earthquake, rain, sudden vibrations due to blasting or flying aircrafts apart from human interventions.

Creep: Extremely slow movement cannot be seen but can be observed indirectly. Usually recognized by presence of trees with curved stems, tilted monuments, distorted fences and bends in lower part of telephone or electric poles on the creeping slopes.

Solifluction: In the periglacial regions where freeze and thaw is common saturated soil or rock debris in active layer may fail at slopes less than even 5^0 inclination.

Caving: A common problem where limestones are present. The seeping waters dissolve the rock and make it cavernous. When the dimensions of the caves become large the roof collapses causing subsidence of overlying structures.

Q3. Describe different methods of landslide hazard evaluation?

Landslide hazard evaluation can be carried out to identify vulnerability of a slope or its parts so that precaution can be taken before any development in a virgin area or to minimize the effect of landslides on already developed or habited area. It is based on identifying different ground characters and causative factors influencing stability of slopes. The Landslide Hazard Maps (LHM) are made by synthesizing data base using GIS on suitable scales. The Important factors to be mapped include: (i) Lithology, (ii) Topography and Slope Morphometric Analysis, (iii) Structural Geology, (iv) Surface Hydrology, (v) Forest Cover and Vegetation, (vi) Anthropogenic Land Use, (vii) Groundwater Condition.

Collation and comparison of these factors can help in identifying the susceptibility of a slope to failure. There are various methods which can be employed for this purpose. Such as methods developed by Central Building Research Institute (CBRI), Roorkee and Bureau of Indian Standard (BIS) in collaboration with Geological Survey of India (GSI) as IS: 14496 Part I and II-2004.

Landslide Susceptibility Score based on identification of different factors and their categories. Each factor is given ranks as per their importance and their categories have been given weightage as given in Table 2. The LSS is being calculated using formula:

$$LSS = \sum (Rank \times Weight)$$

If LSS is greater than 300, susceptibility class is high, LSS from 300 to 200 is for moderate susceptibility and LSS less than 200 is for low susceptibility. The higher value slopes are more vulnerable to landslide as compared to low score ones.

The BIS has given a code for landslide hazard mapping based on ten causative factors with each factor given landslide hazard evaluation factor (LHEF) as 1 or 2, totaling 14 (Table 3). The area to be mapped for landslide hazard zonation is to be divided into different smaller regions using maps of 1: 50,000 to 1: 25,000 for macro zonation and 1: 10,000 to 1: 5,000 for micro zonation. Depending upon the estimated value of each region the entire area can be identified in to five hazard zones as per the following table:

Total Estimated Hazard as per IS 14496 Part II	Zone Category	Zone Description
<4.90	I	Very Low Hazard
4.91 – 7.00	II	Low Hazard
7.10 – 8.40	III	Moderate Hazard
8.41 – 10.50	IV	High Hazard
> 10.50	V	Very High Hazard

Q4. Discuss different measures of landslide mitigation?

The problem of landslides is as such cannot be avoided as it is a natural phenomenon on hill slopes. But, the problem can be moderated or minimized to help inhabitants of hilly and mountainous areas by correctly evaluating the degree of problem. The role of civil engineers of different organizations are of utmost importance as they have to provide safe lifeline buildings and infrastructure apart from guiding people for making safe buildings in terms of suitable location and proper construction technology.

The very first step to counter landslide is the identification of areas prone to landslide and making landslide hazard zonation maps. This can be achieved by taking into account palaeo landslide scars, geomorphology, meteorology, groundwater, weathering state of the rocks, natural vegetation and land use pattern of the region. Depending up on the slope angle, weathering state of rocks, rock types, presence of deformation structures and its orientation with respect to slope, past and recent past occurrences of rock fall and slide etc. will be the deciding factor for development of residential, civil utility structures and infrastructure.

The problem of rock fall, the most common on natural and manmade slopes are tackled by forming rock trap ditches, rock catching nets, rock shelters, wire meshing and chain link fencing. The method to be employed will depend upon the average size of the falling material and probability of fall events, which in turn are function of weathering state of rock mass, number of joints per unit area and verticality of slope. Monitoring of landslide prone area at various spatial scales is an important step as for as prevention and preparedness are concerned. This includes ground surveying at fixed reference points, measurements of rock displacement and crack widening using glued studs and inclinometers in boreholes to monitor any movement. On the basis of landslide zoning map different options can be employed such as slope modification by excavation and filling, reducing pore water pressure and weight of the rock mass by dewatering and by improving drainage. Vegetation turfing and afforestation of slopes to provide root matting which increases tensile strength of soil while deep roots to provide anchorage. Installation of gabion wall, construction of concrete buttresses, retaining wall, dental masonry and concrete spray to provide mass support to slopes. Ground anchors in form of grouted dowels, rock bolts, bored piles and rock anchors provide tensile strength and oppose forces causing landslides.

Under cutting or lateral scouring by river or sea waves called as toe erosion may lead to landslides, can be controlled by erecting gabion walls, laying rip rap or tripods. Many other specific options can be used, especially to keep road/rail tracks safe from rock fall.

Slope Mass Rating given by Romana (1985) based on the following formula can be used to quantify the slope and suggest measures for its strengthening:

$$SMR = RMR_{Basic} + (F_1 \times F_2 \times F_3) + F_4$$

As per the SMR values Romana (1985) defined five slope stability classes shown in following table:

Class No.	**V**	**VI**	**III**	**II**	**I**
SMR Values	0 – 20	21 – 40	41 – 60	61 – 80	81 – 100
Rock Mass Description	Very Bad	Bad	Normal	Good	Very Good
Stability	Completely Stable	Unstable	Partially stable	Stable	Completely stable
Failures	Big planar or soil like complex failure	Planar or big wedges	Planar along joints and wedge failure	Some block to toppling failure	No Failure
Failure Probability	0.9	0.6	0.4	0.2	0

Broad remedial measures can also be suggested by detailed study of the problem, analysis of SMR values and good engineering acumen as per the following table:

SMR Classes	**SMR Values**	**Remedial Measures**
Ia	91 – 100	None
Ib	81 – 90	None to some scaling
IIa	71 – 80	Scaling, provision of toe ditch or fence net
IIb	61 – 70	Toe ditch or fence net, Spot to pattern bolting
IIIa	51 – 60	Toe ditch or fence net, Pattern bolting and Spot shotcreting
IIIb	41 – 50	Toe ditch and wall, Pattern bolting, Systematic shotcreting, Dental concrete
IVa	31 – 40	Anchors, Systematic shotcreting, Dental concrete, Drainage Improvement
IVb	21 – 30	Systematic reinforced shotcrete, Concrete wall, Re-excavation, Deep drainage
V	11 – 21	Re-excavation, Deep drainage, Gravity Wall, Anchored retaining wall with buttresses

Q5. Write a brief on landslide prone areas of India?

India shows varied geological, geographical and climatological nature all along its breadth and length. This has resulted into rich mineral, faunal and floral resources but at the same time it has made the country vulnerable to many natural hazards including landslides. Large scale mass movements are common scene in Himalayan mountain system causing immense loss of life and economy. This high susceptibility is due to active tectonics, high seismicity, steep slopes, complex geological setting, heavy snow and rain fall. Specially with the beginning of monsoon numerous cases of landslides are being reported from Sikkim, Tripura, Meghalaya, Nagaland, Arunachal Pradesh, Assam and hilly tracts of West Bengal apart from J&K, Uttarakhand and Himachal Pradesh. Landslide events are also reported from Western Ghats, Deccan Plateau and Nilgiri hill regions especially during rainy seasons. Many of these landslides have anthropogenic causes as they take place along road and rail network (*Konkan Railways*).

Some recent events of landslides in India are as follows:

a) July 11-12, 1996: Massive landslide in Jaldhaka Valley and Kalimpong hills.
b) June 9, 1997: Hill slope failure and devastation in Gangtok.
c) August 18, 1998: landslide leading to death of 220 people at Malpa, Uttarakhand.
d) July 9, 1999: Landslide in Kurseong town, West Bengal.
e) July 12, 2000: Mumbai Landslides killing 67 people.
f) September 24, 2003: Varunavat Landslide, Uttarakhand affected 3000 people.
g) October 8, 2005: More than 2400 landslide events widely spread in J&K in the aftermath of Muzaffarabad Earthquake.
h) August 14-15, 2007: Catastrophic landslides killing more than 62 people in Dhara Village of Himachal Pradesh.
i) June 13-15, 2013: Kedarnath Landslides, Uttarakhand in the aftermath of cloud bursts caused more than 5700 death and loss of property.

j) July 30, 2014: Malin Landslide near Pune destroying the whole village after heavy downpour.

k) September, 14-15, 2014: Cloud burst, flashfloods and landslide in Srinagar, J&K.

l) 2016: Tawang Landslide, Arunachal Pradesh killing 16 people.

Multiple Choice Questions-

1. A very slow movement of rocky slopes, not easily discernible is termed as

(a) Solifluction
(b) Creep
(c) Slump
(d) Caving

2. Which of the following is related to volcanism

(a) Solifluction
(b) Creep
(c) Nuee Ardente
(d) Caving

3. A rocky slope with almost vertical slopes fails commonly as

(a) Collapse
(b) Rotational Slide
(c) Wedge Failure
(d) Toppling Failure

4. In LSS which factor has highest product of rank and weightage

(a) Hydrology
(b) Slope
(c) Weathering
(d) Lithology

5. Which of the following factor in SMR is related to angle of slope and dip angle

(a) F_1
(b) F_2
(c) F_3
(d) F_4

Suggested Readings:

1. Subinoy Gangopadhyay (2013), Engineering Geology, Oxford University Press, New Delhi.
2. Krynine, Dmitri P and Judd, William R (2005), Principles of Engineering Geology and Geotechnics, CBS Publishers, New Delhi.
3. Tony Waltham (2002), Foundation of Engineering Geology, 3rd Edition, CRC Press, London.
4. Bhawani Singh and R. K. Goel (1999), Rock Mass Classification: A Practical Approach in Civil Engineering, Elsevier, Oxford.
5. Bell, F G (1983), Fundamentals of Engineering Geology, Butterworths, London.
6. Engineering Geology Field Manual (2001), 2nd Edition, Vol. 1, US Dept. of the Interior Bureau of Reclamation.
7. Sathya Narayana Swami (2000), Engineering Geology, Dhanpat Rai & Company, Dew Delhi.
8. Alam Masroor M. (2013), Fundamentals of Engineering Geology and Geo-Engineering, Axioe Books, India.