LANDSLIDE PREPAREDNESS GUIDELINES FOR SAFETY OF BUILDINGS ON SLOPES

Resilient India - Disaster Free India

National Institute of Disaster Management

Ministry of Home Affairs, Government of India

Landslide Preparedness Guidelines for Safety of Buildings on Slopes

ISBN No.: 978-93-82571-30-8

Edition: First, 2019

Author: Surya Parkash, Ph.D

Published by

National Institute of Disaster Management (NIDM), Ministry of Home Affairs, New Delhi-110001

Citation

Parkash Surya (2019): Landslide Preparedness Guidelines for Safety of Buildings on Slopes; published by National Institute of Disaster Management, Ministry of Home Affairs, Government of India, New Delhi-110001, India, pages 80.

Publication Committee, NIDM

Sh. Vikram Gurjar, DC (Trg)

Sh. S. K. Tiwari, Librarian

Ms. Karanpreet Kaur Sodhi, Young Professional

150 YEARS OF CELEBRATING THE MAHATMA

जी. किशन रेड्डी
G. KISHAN REDDY

सत्यमेव जयते

गृह राज्य मंत्री
भारत सरकार
MINISTER OF STATE FOR
HOME AFFAIRS
GOVERNMENT OF INDIA

Message

Landslides are among the major hydro-geological hazards that affect large parts of India, especially the Himalaya, the Northeastern hill ranges, the Western Ghats, the Nilgiris, the Eastern Ghats and the Vindhyas. Our country has a sensational record of catastrophes due to landslides.

NIDM's publication on **"Landslide Preparedness Guidelines for safety of Buildings on Slopes"** is a call for participatory approach involving all the concerned stakeholders, in order to take forward the task of proactive pre-disaster preparedness with emphasis on avoidance, prevention and mitigation-centric strategy.

The efforts of NIDM in providing knowledge-based technical as well as managerial inputs through a practically usable document for the practitioners, functionaries and academicians, is highly appreciable.

I would like to congratulate NIDM for this publication at the opportune time.

(G. Kishan Reddy)

1st November, 2019
New Delhi

Office : Room No. 127, North Block, New Delhi-110 001 Tel. : 23094054 Fax : 23093549

Lt Gen N C Marwah
PVSM, AVSM (Retired)
Member

सत्यमेव जयते

National Disaster Management Authority
Government of India
NDMA Bhawan, A-1, Safdarjung Enclave
New Delhi - 110 029
E-mail : marwahnc.ndma@nic.in
marwahnc@rediffmail.com
Tel. : 011-26701775 Fax. : 011-26701783

Message

There have been numerous incidents of loss of life and property due to collapse of buildings constructed on unstable slopes, especially in the hilly regions prone to landslides.

Handbook on **"Landslide Preparedness Guidelines for Safety of Buildings on Slopes"** will help land use planners, policy makers, financers, professionals, local administrators and other concerned departments to take precautions and preparedness measures before constructing any structure in landslide prone areas.

My compliments to Dr Surya Parkash for bringing out this handbook the essence of which can be embedded in the building codes for hilly regions of the Country.

New Delhi
28 October 2019

(Lt Gen N C Marwah)(Retd)
Member, NDMA

nidm
Resilient India : Disaster free India
Maj Gen Manoj Kumar Bindal VSM
Executive Director

सत्यमेव जयते

राष्ट्रीय आपदा प्रबंधन संस्थान
(गृह मंत्रालय, भारत सरकार)
National Institute of Disaster Management
Ministry of Home Affairs, Govt. of India
A-Wing, 4th Floor, NDCC - II, Jai Singh Road, New Delhi - 110001

Foreword

The rising trend in the incidences and impacts of landslides due to their sudden, frequent and widespread occurrence in the hilly terrains poses serious challenges and threats to life, economy, environment, infrastructures, resources, utilities and services. Despite all efforts for avoidance, prevention and mitigation of these landslides risks, the dire need for preparedness and quick response cannot be ruled out. Besides primary landslides, there have been instances of secondary landslides due to earthquakes and floods in the hills. NIDM has been mandated by Disaster Management Act 2005, Chapter 7, Section 42 and 43 to provide training and enhance human capacity for disaster risk reduction and resilience. Keeping this in mind, an attempt has been made to formulate landslide preparedness guidelines specific to buildings for safety of human lives and protection of properties.

The document *"Landslide Preparedness Guideline for Safety of Buildings on Slopes"* has been developed to provide a basic idea about landslides, triggering factors and mitigation measures to abate landslide hazards and risks.

It consists of various avoidance, prevention and mitigation practices that can be followed easily and focuses on generalized idea of planning and site selection to construct houses in landslide-prone areas, to minimise the vulnerability towards landslide hazards. It takes cognizance about the warning signs of landslides, do's and don'ts in pre, during and post landslide phases.

The document is going to benefit the readers and other stakeholders including the geologists, civil engineers, architects, planners, developers. It will also help in learning about various potential measures for prevention and mitigation of landslide risks to the buildings on susceptible hill slopes.

MKBindal

Major General Manoj Kumar Bindal, VSM

आपदा प्रबंधन महाविचार: पूरा भारत भागीदार

फोन / Ph: +91-11-23438285, • फैक्स / Fax: +91-11-23438286, • ई मेल / E-mail:ed.nidm@nic.in, • वेब साईट / Website : www.nidm.gov.in

Preface

Hazard in any form hampers the normal system, structures, services and functions of our lives. Awareness about these hazards is a key for avoidance, prevention and mitigation of their impacts.

On account of the geographical position, geodynamics situation and climatic conditions of India, landslides and the associated risks are frequent and widespread in the country. In addition to natural factors, human intervention in terms of construction activities, mining, deforestation and urbanization as a result of socio-economic demands, has worsened the situation.

On a rough estimate, nearly 15% of India's landmass or 0.49 million sq km area is prone to landslide hazards. It has taken toll of precious lives and lead to social, economic and environmental losses. Impacts of this hazard are long termed that include population displacement, loss of livelihood, psychological impacts, disruption in social life and harm to infrastructure leading to hardships for the affected population and negative impacts on the natural environment.

The document *"Landslide Preparedness Guidelines for Safety of Buildings on Slopes"* has been prepared to make people aware of landslide and its causes with main focus on avoidance, prevention and mitigation measures, that common people can understand and implement to protect themselves from landslides, especially those who are living on unstable slopes or their surroundings. The document would help to counter the ignorance and human mistakes that give rise to landslide problems. It is an awareness guide with emphasis on better understanding of lanslide hazards with their avoidance, prevention and mitigation for planning, development, maintenance and sustenance of slopes, structures, infrastructures and services with reduced risks and enhanced the resilience of people against disasters.

In preparing the document, information has been drawn from a number of publications, research papers and various other sources. The author would like to acknowledge with gratitude and thank to publishers and authors of those publications for permitting the use of relevant information in this document in humanitarian interest.

Surya Parkash
Author

Acknowledgement

A work is always completed with joint efforts of a supporting team. It is my pleasure to thank all those who helped me in successful completion of this document.

First of all I would thank Major General Manoj Kumar Bindal, VSM, Executive Director, National Institute of Disaster Management (NIDM) for encouraging me to publish a document that could bring out the problems with solutions related to landslides. His time and endeavour helped me to accomplish this task. He was a constant source of inspiration during the entire working on this document. His constant advice and support helped to bring "*Landslide Preparedness Guidelines for Safety of Buildings on Slopes*" to its present form.

I would also like to sincerely thank Ms. Rajni Sekhri Sibal, IAS, Secretary, Department of Fisheries (Formerly Additional Secretary (DM), MHA and ED NIDM) for motivating me to take an initiative to prepare this book.

Sincere heartfelt thanks are due to reviewers, Lt. Gen. Retd. Sh. N. C. Marwah, Member, National Disaster Management Authority, Government of India; Dr. Shailesh Agarwal, Executive Director, Building Materials & Technology Promotion Council (BMTPC) and Shri Sanjeev Sharma, DDG, Geological Survey of India (GSI).

Thanks are also due to Ms. Baljindar Kaur, former Jr. Consultant, NIDM who helped in preparing the materials for the book as well as to Mr. Anil Kathait, Ms. Harjeet Kaur, Mr. Raju Thapa and Ms. Karanpreet Kaur, Young Professionals, NIDM for editing and proof reading.

I would also thank all the staff members of NIDM as without their support and cooperation, the work would have not been possible.

Also, I am thankful to all the resources from where we have garnered our data and utilised the information in preparing this document. The completion of this document enables us to draw invaluable knowledge related to the subject.

Surya Parkash
Head, Geo-Meteorological Risks Management Division
NIDM, New Delhi

Glossary

Abutments: A structure built to support the lateral (horizontal) pressure of an arch or span usually at the ends of a bridge or drain.

Berm: A raised bank or terrace bordering a river or canal.

Catastrophic: Extremely unfortunate event causing sudden great damage.

Channel drain: A course or pathway through which water is guided to a particular place like natural stream.

Check valve: It is a valve having two openings in the body one to let fluid enter and other to let fluid leave. It is provided to check flow of water and can be closed accordingly.

Chute: A sloping channel or slide for conveying things to a lower level.

Clay: Clay is a cohesive soil having particles smaller than 2 micron (0.002 mm) with crystalline structure. The clay particles are flat or plate like in shape.

Cliff: A steep rock face.

Cloudburst: Cyclonic winds compress the clouds and forced nucleation amounts to sudden precipitation. Thus, all the water from the clouds pours out with great velocity and is called cloud burst.

Cohesion: The attraction or bonding force between the particles of fine-grained soils that defines the strength of soil.

Compaction: It is the process of increasing the density (or unit weight) of a soil by rolling, tamping, vibrating or by other mechanical means. It is proportional to strength of soil.

Density: The mass per unit volume of soil is called density of soil. It is a degree of compactness of soil.

Differential settlement: Uneven, downward movement of foundation of structure due to varying soil or loading conditions resulting in cracks in foundation and distortions in building.

Earth: Here, earth is referred to the soil constituting the material of slope.

Engineered buildings: Buildings constructed with proper planning and design practices of architecture and civil engineers, followed with supervision.

Erosion: The process by that the surface of earth is worn away by action of water, glaciers, winds, waves, etc.

Fill: It is earth placed in excavation or other are to raise the elevation.

Fissures: A narrow opening produced by separation of parts.

Fly ash: It is one of the residues generated in combustion, and comprises the fine particles that rise with the flue gases and is added to cement to improve its properties.

Frost zone: It is zone of frost depth or freezing depth, the depth to that the groundwater in soil is expected to freeze. The frost depth depends on the climatic conditions of an area.

Geology: The science that deals with the physical structure and substance of the earth, their history, and the processes that act on them and factors related to geology are geological factors.

Grade of concrete: Grade defines the strength of concrete. More the grade of concrete more is the strength of material. Minimum grade of concrete used is M20 for reinforced concrete structures.

Graded sand: Gradation means distribution of different size groups within a soil sample.

Gullying: Forming of a deep channel or ditch cut in the earth by running water after a prolonged downpour.

Haphazard construction: Construction done with lack of planning, without considering soil quality, building's behavior during disaster and thus is irregular and random.

Hazard: A condition with the potential for causing an undesirable consequence.

Inertia: Inertia is the resistance of any physical object to any change in its state of motion, including changes to its speed and direction.

Kerb: A stone edging to a pavement or raised path.

Masonry: Masonry is the building of structures from individual units like bricks, stones, marble; blocks, etc. lay in and bound together by mortar.

Mitigation: Mitigation is the effort to reduce loss of life and property by lessening the impact of disasters.

Peat: It is an organic soil having fibrous aggregates of macroscopic and microscopic particles. It is formed from vegetal matter. It is highly compressible and not suitable for foundations.

Percolation: Percolation is process of a liquid passing through a porous substance or small holes; filter.

Plasticity: It is a property of dine grained soils due to that a soil having adequate water content is able to flow and can be re moulded without breaking apart.

Pore pressure: It is the water pressure developed in the voids (empty spaces) of soil mass. The shear strength reduces due to pore pressure as excessive stress is reduced.

Precipitation: It is rain, snow, hail or sleet i.e., any product of condensation of atmospheric water vapours that deposit on ground surface.

Friction: The resistance that one surface or object encounters when moving over another.

Permeability: Property of a material that let fluids pass through them without changing in chemically or physically.

Prestressed concrete: Concrete in that reinforcing steel bars are stretched and anchored to compress it and thus increase its resistance to stress.

Resisting force: Resistance force is the force that an effort force must overcome in order to do work on an object. It is the force that resists change in the body of an object.

Rubble masonry: Rubble masonry is rough, undressed building stone set in mortar, but not laid in regular course.

Sand: It is a type of coarse grained soil whose particles size range between 0.075mm and 4.75 mm. Sand is cohesion less and has high internal friction.

Saturation: A condition in that all easily drained voids (pores) between soil particles are temporarily or permanently filled with water.

Seepage: Seepage is the flow through an earth mass under pressure. It is the quantity of water flowing through a soil deposit or soil structure or foundation.

Self-cleansing velocity: The minimum velocity at that no solid gets deposited in the invert of the drain pipe.

Shear strength: It is the ability of soil to resist shearing stresses developed within a soil mass as a result of loading imposed onto the soil. It is the maximum résistance that develops just before the failure under shear. It is the function of cohesion.

Shotcrete: Concrete or mortar that is pumped through a hose and projected at high velocity onto surface.

Shrinkage: Soil undergoes a volume change when water content is changed. It shrinks when water content decreases.

Silt: It is a type of fine grained soil with the particle size smaller than 0.75 mm, but whose mineralogical composition remains same as that of the parent rock does not contain clay minerals.

Swelling of soil: When water is added to soil that has shrunk, the elastic expansion of soil takes place called swelling and it decreases strength of soil.

Tensile failure: Tensile failure occurs when the material's capability of being stretched or drawn ends causing cracks or complete breakage.

Vulnerability: The diminished capacity of an individual or group to anticipate, cope with, resist and recover from the impact of a natural or man-made hazard is called vulnerability.

Weathering: Wearing away or change in the appearance or texture of (something) by long exposure to the atmosphere is called weathering.

Contents

List of Figures

List of tables:

INTRODUCTION

"KNOW disaster NO disaster"

Landslide is the most commonly occurring hazard in north and north-eastern Himalaya, Western Ghats, Eastern Ghats and Vindhyan, India. It takes massive toll of human lives and lead to huge economical losses every year besides damages to environment, resources infrastructure and services. The need of the hour is to be prepared to minimise the incidences and impacts of landslides.

To begin with causes of landslides, their characteristics and impacts are to be understood so that steps for mitigation could be followed accordingly. The moderation steps include checking for slope failure, soil erosion, rising ground water levels, drainage problems and check for building failure including foundations. The importance of the individual level in extenuation has to be realised and collective synergized steps can be followed easily or brought into action through authorities, planners and developers.

There are various materials used for construction purposes in hilly areas, but the most important part is following the proper steps for construction so that it could prove to be beneficial in the long run and, particularly when disaster strikes.

There are some basic things that can be observed before landslides and acts as a warning signs for the individuals. Some do's and don'ts especially for the people living in hilly areas can be followed in pre, during and post landslide phases.

MALIN LANDSLIDE

A major landslide catastrophe occurred in the Malin village of Ambegaon Taluk in Pune district, Maharashtra in the early morning of 30^{th} July 2014 when the people of the area were sleeping in their houses. The cloudburst that followed the two days incessant rains that saturated the soil along up slopes of the village and it developed as loose mud and eventually flowed down gaining momentum as gushing mud flow and swept terraces, retaining walls and ultimately the hutments of the village and engulfed >150 persons within it. More than 40 houses got amalgamated in the landslide debris. The landslide initiated from the top of the hillock blocked the road with debris.

It was one of the three high-risk villages in the region marked "Ecologically Sensitive Areas" by the Kasturirangan Committee Report, 2013 on Western Ghats. The Western Ghats Expert Ecology Panel (WGEEP) Report and High Level Working Group Report (HLWG) management of the region have placed Malin and the neighborhood in Ecologically Sensitive Zone I and Ecologically Sensitive Area (ESA) respectively.

1. ABOUT LANDSLIDES

When slope forming materials that constitute mass of rock, debris or earth, moves downwards and outwards, under the influence of gravity and triggered by various factors, it is termed as landslide.

Area of landslides occurrence

Landslides mostly occur in areas having unstable slope i.e., a surface having one end or side at a higher level than another.

They often take place in conjunction with heavy rainfall, earthquakes, floods, cloud burst, mining, excavation, erosion or with loading/unloading of slopes.

Landslides of different types occur frequently in the geo-dynamically active spheres in the Himalayan and North-eastern parts of India as well as relatively stable spheres in the Western Ghats and Nilgiri hills in the southern part of the country.

The occurrence of landslides has also been reported in the Eastern Ghats, Ranchi Plateau, and Vindhyan Plateau. In all, states namely Himachal Pradesh, Uttarakhand, Arunachal Pradesh, Assam, Meghalaya, Mizoram, Manipur, Nagaland, Sikkim, Tripura, Kerala, Karnataka, Tamilnadu, Andhra Pradesh, Goa, Maharashtra, Madhya Pradesh, Chhattisgarh and parts of the Union Territories of Puducherry, Jammu & Kashmir, Ladakh and Andaman & Nicobar Islands of the country are affected by this hazard.

How to determine the slope gradient

The gradient of slope is defined as vertical distance over horizontal distance describing steepness and direction of the slope.

$$\text{Angle, } \tan\theta = \frac{\text{Vertical distance}}{\text{Horizontal distance}} = \frac{V}{H}$$

$$\boxed{\theta = \tan^{-1}\frac{(V)}{(H)}}$$

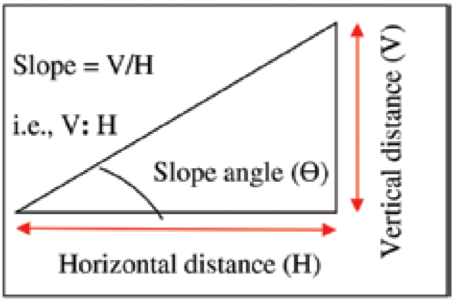


Fig 1.1: Determining slope gradient

Slope gradients are defined by IRC as below

- Steep slope (> 60°)
- Mountainous slope (25°-60°)
- Rolling slope (10°-25°)
- Plain slope (up to 10°)

Slopes greater than 30° are generally prone to landslides owing to other triggering factors.

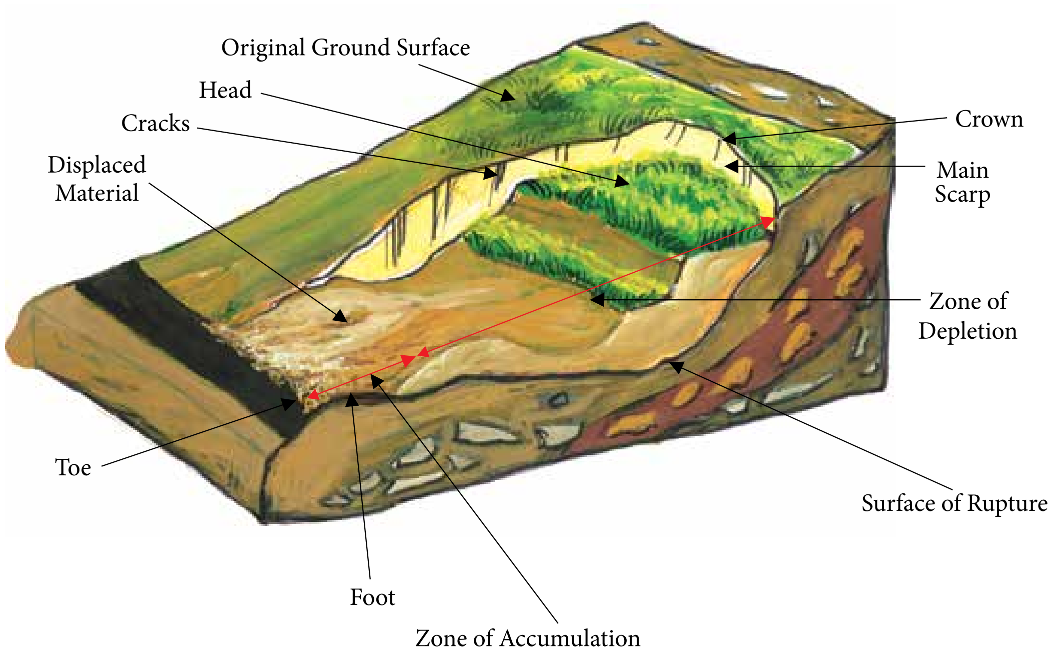


Fig. 1.2: Nomenclature for landslide
(Source: http://pubs.usgs.gov/circ/1325/pdf/C1325_508.pdf)

<u>Nomenclature of landslides</u>

1. *Main scarp:* A steep surface on the undisturbed ground around the periphery of the slide, caused by the movement of slide material away from the undisturbed ground is the *main scarp*. The projection of the scarp surface under the displaced material becomes the surface of rupture.

2. *Crown:* The material that is still in place, practically undisturbed and adjacent to the highest parts of the main scarp is termed as *crown*.

3. *Head:* The upper part of the slide material that is along the contact between the displaced material and the main scarp is *head*.

4. *Toe:* The margin of displaced material most distant from the main scarp is *toe* of landslide.

5. *Displaced material:* Material uprooted from its original position on the slope by movement in the landslide is called *displaced material*. It forms both the depleted mass and the accumulation.

6. *Surface of rupture:* The *surface of rupture* is the surface forming (or has

formed) the lower boundary of the displaced material below the original ground surface.

7. *Original ground surface:* The surface of the slope that existed before the landslide took place is *original ground surface*.

8. *Zone of accumulation:* The area of the landslide within that the displaced material lies above the original ground surface is termed as *zone of accumulation*.

9. *Zone of depletion:* The area of the landslide where the displaced material lies below the original ground surface refers to *zone of depletion*.

1.1 Volume of Landslide

The length, width and depth of displaced material can be measured directly even if parts of surface of rupture are hidden.

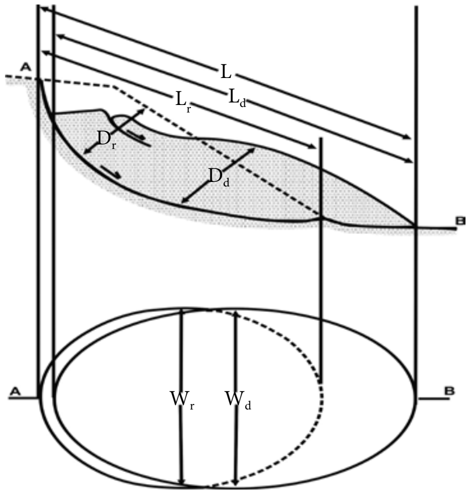


Fig. 1.3: Landslide features and dimensions used for volume calculation

L_d = Length from tip of displaced material to its top.

L_r = Maximum length of rupture surface, measured from toe of surface of rupture to crown

L= Total length, measured from tip to crown

W_d = Displaced mass, measured across the original ground surface in direction perpendicular to the lengths L_r and L_d

D_r = Maximum depth D_r, estimated from original ground surface in a direction perpendicular to it

D_d = Thickness of the displaced material, measured perpendicular to the surface of the displaced material

Therefore, volume, V, of displaced mass is measured in cubic meters considering half the ellipsoid, across major axes.

$$V = (1/2)x(4/3)x(1/2)xL_d xD_d xW_d = (1/6)xL_d xW_d xD_d$$

1.2 State of Activity

State of activity defines the time of occurrence of landslides taken as guide to know the places of impending landslides.

- Active landslides: Landslide that is currently moving or has moved in present annual cycle of seasons.
- Suspended landslides: Landslides that have moved within last annual cycle of seasons but that are not moving at present.
- Inactive landslides: Landslides that last moved more than one annual cycle of seasons ago. They are further divided into dormant and abandoned landsides.
    - Dormant landslide: If the cause of movement still remains, it is dormant landslide.
    - Abandoned landslides: If cause of movement doesn't remain, as river eroding its toe has changed its course itself, it is abandoned.
- Stabilised landslides: If the toe of slope has been protected against erosion by remedial measures, it is stabilized.
- Relict landslide: Landslides that have developed again under changing geological or climatic conditions are relict landslides.

1.3 Characteristics of Landslides

Based on failure process and materials involved, landslides are classified in five types:

Table 1.1: Landslides classification based on movements and materials

Type of Movement		**Type of Material**		
		Soils		**Bed Rock**
		Predominantly fine	**Predominantly coarse**	
Falls		Earth/Soil fall	Debris fall	Rock fall
Slides	Rotational	Earth/Soil slump	Debris slump	Rock slump
	Translational	Earth/Soil slide	Debris slide	Rock slide
Topples		Earth/Soil topple	Debris topple	Rock topple

Lateral Spread	Earth/Soil spread	Debris spread	Rock spread
Flows	Earth/Soil flow	Debris Flow	Rock flow
Creep	Soil creep	Debris creep	
Complex	Combination of two or more principal types of movements		

1. Falls

Landslide is referred as fall when earth/debris/rock move down with rapid to extremely rapid movement after detaching from steep slope due to loss of cohesive forces.

Free fall if slope exceeds 76 degrees and rolling at or below 45 degrees.

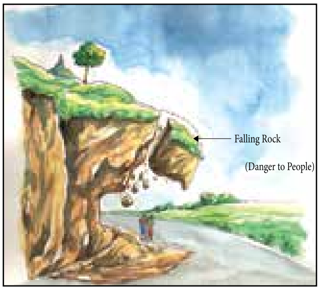


Fig.1.4: Fall of rock

2. Slides

Movement of material along a recognizable shear surface, slides are of two types

Rotational: When material rolls down the slope due to weakening of cohesive forces, it is termed as *Rotational slide*.

Translational: When material simply slides down due to fissures or failures in joints, it is termed as *Translational slide*.

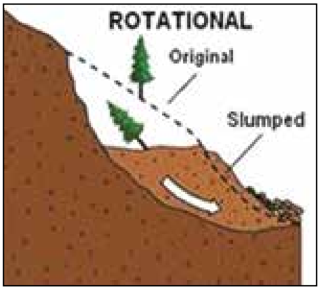


Fig. 1.5: Rotational slide

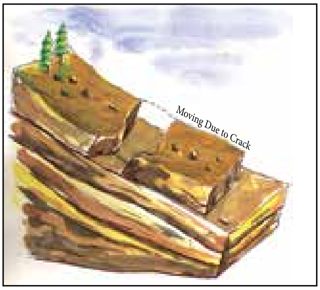


Fig. 1.6: Translational slide

3. Topples

Over end motion of rocks or earth/debris on a down slope due to disturbance or cracks is known as *toppling*. Topples range from extremely slow to extremely rapid movements.

4. Lateral Spreads

When *cohesive rock or soil mass* spreads horizontally over a deforming mass of softer underlying material due to shear or tensile failure it is termed as *Lateral spread*.

Fig. 1.7: Toppling of rocks

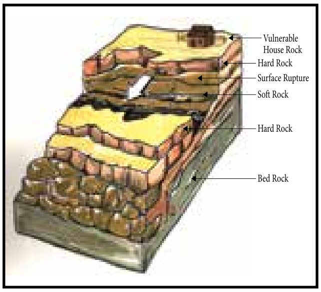


Fig. 1.8: Lateral spread

5. Flows

When failure transforms the material into a viscous fluid consisting of soil and rock particles suspended in water material, it *flows* down.

6. Creep

When slope progresses down gradually (often at extremely slow rates) usually a few millimeters per year due to disturbance in material of slope, it is defined as creep.

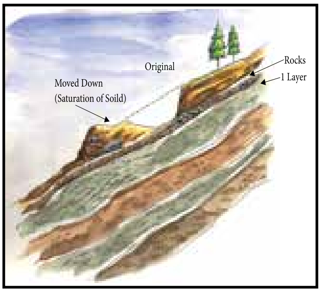


Fig. 1.9: Flow

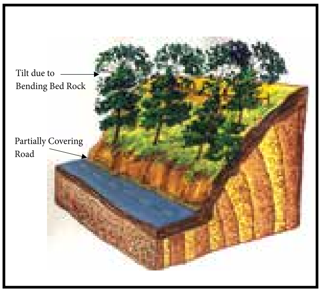


Fig. 1.10: Creep

7. Complex

Combination of one or more of the above mechanisms of landslides is termed as *complex* as the nature of failure process is not consistent and changes with time.

1.4 Landslides in India

Landslides are among the major hydro-geological hazards that affect large parts of India, especially in the Himalaya, the northeastern hill ranges, the Western Ghats, the Nilgiris, the Eastern Ghats and the Vindhyas.

A rough estimate of landslide losses in the country indicates that about 500 lives are lost annually with economic damages up to 4 billion INR.

Table 1.2: Probability of Landslides occurrence in India

Region	**Incidences of Landslides**
Himalaya	High to very high
North-eastern Hills	High
Western Ghats and the Nilgiris	Medium to high
Vindhayachal	Low

India has a sensational record of catastrophes due to landslides, unique and unparallel.

- The Darjeeling floods of 1968 destroyed vast areas of Sikkim and West Bengal by unleashing spate of landslides, causing considerable death and destruction.

Fig. 1.11: Darjeeling floods induced landslides
(Source: http://savethehills.blogspot.in/2008/06/lest-we-forget-oct-1968-in-pictures.html)

Fig. 1.12: Amboori landslide
(Source: http://www.thehindu.com/2001/11/11/stories/0411211l.htm)

- In Nilgiri hills, during October–November 1978, 90 people died due to landslides.
- The Malpa rock avalanche tragedy of 18 August 1998 killed 220 people and wiped out an entire village of Malpa on right bank of river Kali in Kumaun Himalaya, Uttarakhand
- The Amboori landslide of 9 November 2001 in the state of Kerala killed 23 people.
- The Varunavat landslide of Uttarkashi initiated on 23 September 2013 and lasted for 15 days endangered Uttarkashi township.
- The Konkan landslide (2005) in Konkan Plain of Maharashtra killed 190 people.
- Landslides in Bhavi village of Ghanvi in Himachal Pradesh (2007) triggered from cloudburst, killed 52 people.
- The landslide in Malin village (2014) approximately 45 km NW of Ghorhegaon, and 120 km NNW of Pune, Maharashtra killed more then 150 people and washed away the whole village.
- Landslides along the National Highway (NH) 1A and NH-1B in Jammu and Kashmir, the Rishikesh-Badrinath pilgrimage route in Uttarakhand, highways and roads in Darjeeling and Sikkim, and the Dimapur-Imphal and Shillong-Silchar National Highways are also prominent.

Many reported and unreported landslides take toll of life, property causing widespread destruction and economical and social losses.

There are some slides that are stable at some time of the year and problematic at other time.

(Source: http://www.chinadaily.com.cn/photo/2010-04/27/content_9781843.htm

(Source: http://indiatoday.intoday.in/story/pune-landslide-malin-village-buried-under-debris-heavy-rains/1/374887.html)

Fig.1.13: Scenario after landslide

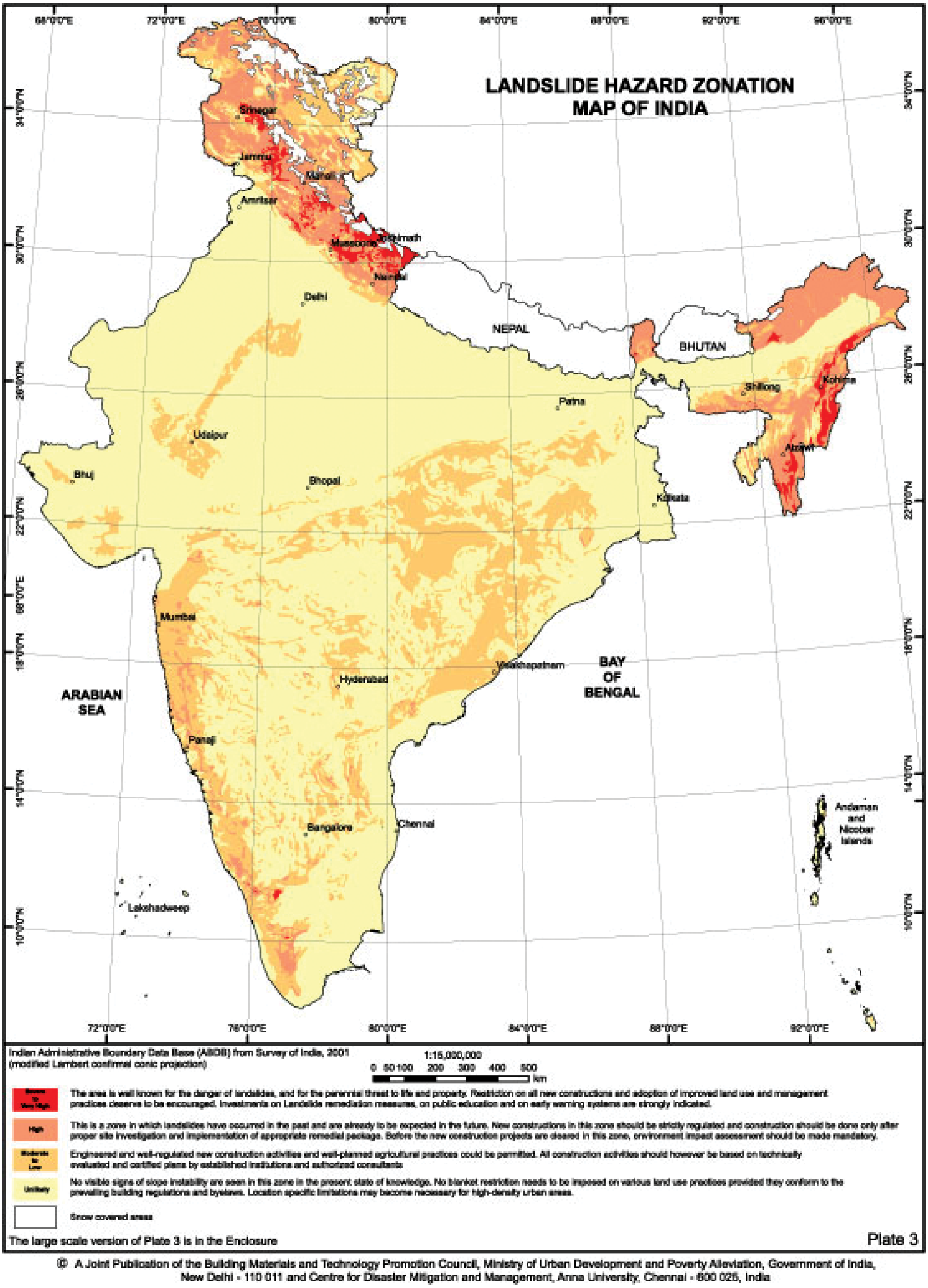


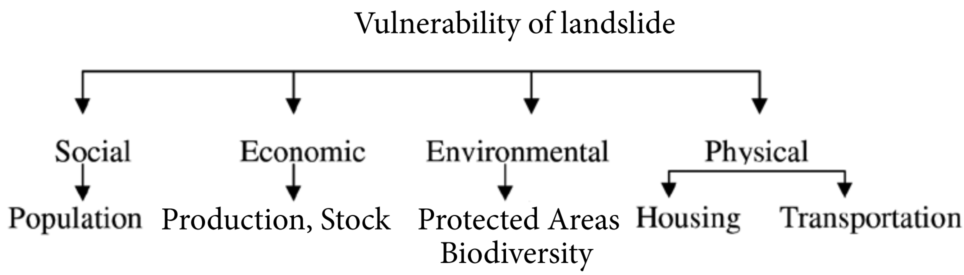
Fig. 1.14: Landslide hazard zonation map of India
(Source: BMTPC)

BMTPC: Vulnerability Atlas - 3rd Edition: Peer Group, MoHUA,GOI: Map is Based on digitised data of SOI; Landslide Incidence data GSI; Annual Rainfall data IMD. Houses/Population as per Census 2011;
* Houses including vacant & locked houses. Disclaimer: The maps are solely for thematic presentation.

Fig. 1.15: Landslide incidence map of India
(Source: BMTPC)

1.5 Vulnerability to Landslides

Vulnerability is defined as the consequences or the results of an impact of a natural force. It is measured in terms of loss either on a metric scale in terms of given currency or on a non-numerical scale based on social values on perceptions and evaluations.



Some points to be kept in mind to assess vulnerability:

- Vulnerability of different elements at risk varies for similar processes- a house have same vulnerability to fast and slow moving landslide but persons living in house have low vulnerability to slow moving landslide as they can move outside that is difficult in fast moving landslide.
- Probability of a person being present during landslide event is variable – people would be in the house during night but in morning parents will go to office and children will go to school leaving fewer people in house.
- Different groups of humans have different coping potentials- elderly and handicapped would find difficult to escape as compared to adults and children.
- Early warning systems affect vulnerability of people- people might be able to escape to safer places if early warning is given.
- Spatial probability of landslides occurrence varies – as though landslide occurs in a predicted zone but a small building or person affected is different for a single rock fall or for a debris flow affecting larger areas.

Keeping all these in mind, the vulnerability to landslides is assessed according to different situations, type of landslide occurred and time of occurrence.

1.6 Causes of Landslides

Slopes are made up of rocks, earth and debris. When gravity force that drives these materials (in effect to slope angle, climate, slope material and water) to fall exceeds the resistance force that is due to shear strength of material, cohesion and internal friction leads to instability and loosening of the materials. This entire process triggers landslide. The factors responsible for such occurrence are geological and anthropogenic factors.

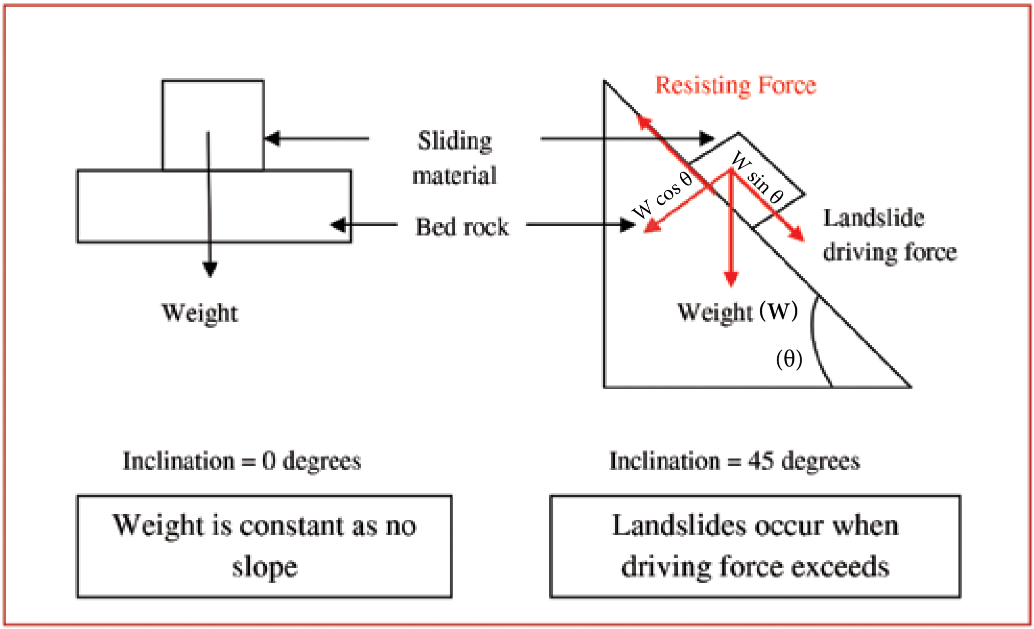


Fig. 1.16: Reasons for triggering of landslide

1.6.1 Geological Factors

i. Weak strength of the materials below the ground surface.

ii. Saturation of slope material from rainfall or seepage making it loose.

iii. Undercutting of cliffs and banks from wind or water erosion.

iv. Vibrations caused by earthquake.

v. Freeze and thaw weathering:

The water seeps into pores of rocks and due to extreme climatic conditions, get freeze inside, causing expansion and affecting the surrounding material, making it weak. As this process continues due to changing weather, it causes weathering of materials causing cracks and making it vulnerable to fall.

vi. Sheared, jointed, or fissured material and discontinuity in orientation.

vii. Shrink-and-swell weathering:

In wet conditions, pores of soil get filled with water and in dry conditions, the water evaporates, air enters the voids of soil and thus soil shrinks due to volume reduction. This leads to cracks on surface of soil.

viii. Loosening of rock masses from vegetating growth within joints.

ix. Failure due to instability of steep slopes as chance of increasing sliding force is more. Slopes greater than 30° are at risk.

x. Dams formed by landslides: Displaced materials (rock, soil, and (or) debris) fills the waterway and act as a natural dam, block the flow of the river and creates flood upstream. These dams are easily eroded by water pressure on the upstream side of landslide dam that may cause the flash floods on the downstream side, potentially resulting in exorbitant damages and losses. Consequently, landslides take place further in weak areas.

Fig. 1.17.: Undercutting of cliff

Fig. 1.18: Cracks in rocks – Freeze and thaw weathering

Fig. 1.19: Landslide forming dam in river.

Fig. 1.20.: Tension cracks

Fig. 1.21: Shrinking of soil

Fig. 1.22: Fallen rock from detached mass

1.6.2 Anthropogenic Factors

1. *Construction Practices*

Rapid expansion of settlements and non-engineered building construction in hills increases the load on already deteriorated slopes and no proper measures are taken, giving rise to landslides.

- Construction of roads
    1. Excavation of slopes for construction purposes to create space for road template involves cutting and filling.
    - In cutting, material is removed from particular place for space.
    - In filling, material is placed at the location to make it rise or stable for construction.

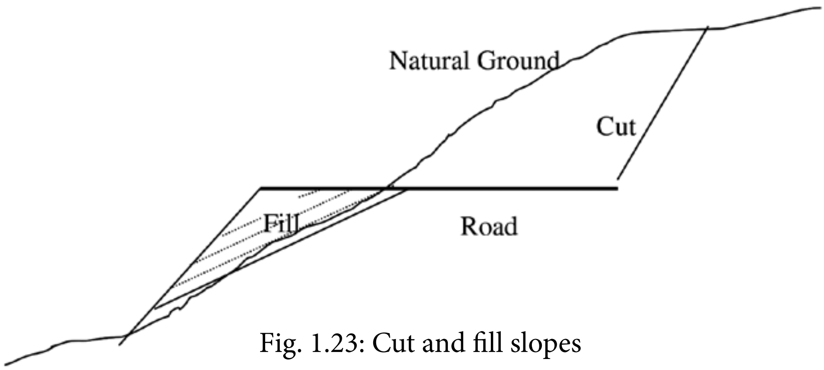


Fig. 1.23: Cut and fill slopes

Failures due to cutting and filling accounts to following:

- If slope is not carefully flattened i.e., safe gradient is ignored.
- If fill material is not compacted properly.
- If cuts in natural soils encounter groundwater or zones of weak material.
- If cut or fill is done near stream and channel crossing.

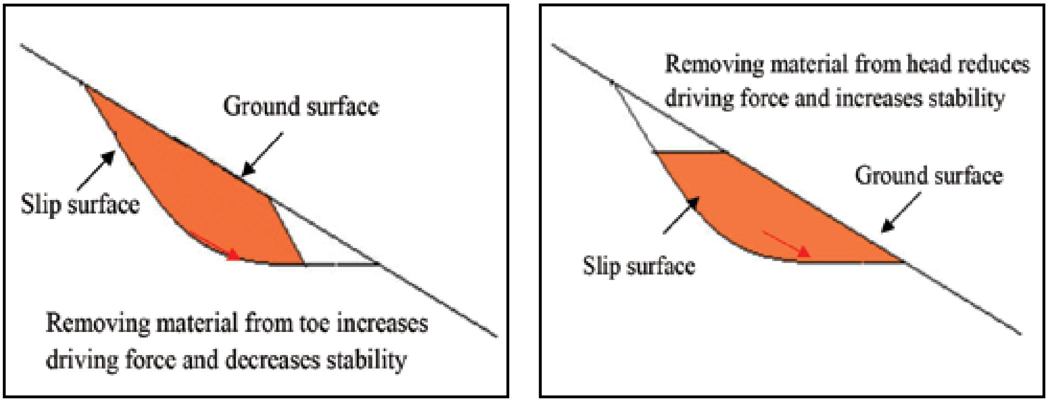


Fig. 1.24: Stability of slope

2. Continuous horizontal vibrations from heavy traffic along the road and blasting or excavation done for construction gradually destabilise the slopes. *The 434 km hill road from Srinagar to Leh has cut down the time of journey from 16 days to 2 days but had created the problem of landslides.*

- Construction of dams
  - Construction of dams leads to excavation of rock/soil and improper disposal of this muck, leads to increased silt in river and its surface velocity. The increased surface velocity of water erodes off the base of toe of slopes leading to landslides.
  - Rivers are carrying incredibly large amount of sediment at the rate of 16.5 hectare meter per hundred square kilometer of catchment area to lakes and reservoirs.
- Construction of houses
  - Indiscriminate construction puts excessive pressure on soil especially if bearing capacity of soil is not taken into account before construction. Strength of the soil decreases with time due to fatigue leading to landslides.
- If trenches constructed during various construction practices are not backfilled properly and compacted, can slide.
- Earth exposed during the construction of a buttress can cause erosion and siltation when drainage and soil retention methods are not utilised during grading.

Fig. 1.25: Construction of dam in Arunachal Pradesh and muck disposed at side of river

Fig. 1.26: Haphazard construction in Uttarakhand
(Source: http://hillpost.in/2012/04/unplanned growth-mars-uttarakhand-development/43517)

3. *Drainage problems*

No proper drainage of water makes it accumulate in soil and increases underground water and pore water pressure. This decreases the strength of soil making it vulnerable to slide and also increase in groundwater puts pressure on foundation of buildings.

Drainage problem occurs due to following reasons

- Interference with or changes to natural drainage systems due to terraces and other construction.
- No proper drainage system for excess surface storm water during high intensity rainfall or flash flood.
- Ignoring leakage of water or sewerage from pipes.
- Continuous unchecked water flow on slopes.
- Clogging of drain pipes/culverts of inadequate capacity.

4. *Deforestation*

- Clearing vegetation makes the soil vulnerable to erosion and loss of cohesive forces (forces that bind the soil together) as roots of trees/plants keep the soil in place and also maintains water in soil.
- During the monsoon, rain water comes down to the plains unchecked, causing swelling of streams leading to flash floods, that in turn triggers landslides.
- Podu/jhoom cultivation practiced mostly in South/Northeastern states leads to deforestation. In this practice, growing two or more

Fig. 1.27: Barren land vulnerable to erosion

Fig. 1.28: Podu cultivation in Vishakhapatnam leading to deforestation.
(Source: http://www.thehindu.com/news/cities/Visakhapatnam/podu-cultivation-degrading-forest-cover/article3737719.ece)

annual crops and then burning the land, making the land abandoned till next seed filling makes it lose the fertile nature and no more forest growth takes place afterwards.

- Rural people cut natural forests, woodlands and shrublands to obtain timber, fuel wood and other forest products making it unsustainable as it usually, exceeds the rate of natural regrowth.

5. *Erosion*

- Erosion is a natural process caused by wind, water and many other external forces, but due to deforestation, construction and agricultural practices, soil gets more vulnerable to erosion.
- In the past, shifting cultivation was a sustainable form of land use, at a time when low population densities allowed forest fallow periods of sufficient length to restore soil properties. Population increase and enforced shortening of fallow periods has made it unsustainable.
- Shifting cultivation is found in the hill areas of northeast India, where it causes soil erosion and decline in soil fertility.
- Under agriculture, areas are cultivated with root crops like potato, ginger, cardamom and onions that are harvested just after monsoons in the month of September–October and for the remaining period, land remains barren leading to soil erosion.

6. *Mining*

- Blasting done for mining produce vibrations affecting soil particles making the slope unstable.

Fig. 1.29: Erosion of soil.

Fig. 1.30: Coal mining in India

Fig. 1.31: Blasting activity (Source: http://www.conservationindia.org/news/immense-environmental-toll-of-coal-mining-in-india)

- Inadequate disposal of muck, excavated material from mining, cause man-made landslides.
- Quarrying and mining in Doon Valley, Jhiroli have inflicted heavy damage to slopes.

CAUSES OF MALIN LANDSLIDE

Triggering factor for Malin Landslide was continuous heavy rainfall that saturated the soil and led to flow.

Long Term Causes:

- The Union Ministry of Environment and Forests (MoEF) notified Malin in November 2013, as Ecologically Sensitive Area and recommended a no-development policy.
- It was a warning to hold back all activities in the ecologically-fragile regions, but ignored by local and state authorities.
- Besides warning, flattening of hill slope with heavy machinery for agricultural purposes and also for windmill project was carried on that aggravated the crumbling of hill top.
- Cracks were observed on the ground where the soil was washed downhill during the "earthslip" that imply an improper rainwater drainage system.

Therefore, unscientific mechanised terracing, muck dumping, slope instability, deforestation and hampered drainage, magnified the impact on a naturally vulnerable, high rainfall region.

2 EARTHQUAKE AND PRECIPITATION INDUCED LANDSLIDES

Earthquake and precipitation (rainfall, cloudburst, snow avalanche etc.), triggers the slope instability resulting in landslides.

2.1 Effect of Earthquake

Earthquake forces shake the ground that sets underlying rock into motion. This motion is communicated to soil cap but the inertia of soil prevents it to respond instantly. Consequently,

- Liquefaction of soil.
- Failure of slope due to loss of pressure of soil on the rock.
- Development of tension cracks.
- Lateral spreading of soil.

2.1.1 Liquefaction

- The liquefaction phenomenon takes place, when the structure of a loose, saturated (pores filled with water) sand breaks down due to rapidly applied loading leading to densification.
- In an earthquake, there is not enough time for the water in the pores of the soil to be squeezed out. Right away, the water gets "trapped" and reduces the contact forces between soil particles, making the soil deposit soft and weak, liquid type behaviour.
- Ultimately, it triggers the flow of water with pressure towards the ground and carries a significant amount of soil with it, that loosens foundation and result in collapse of the building due to differential settlement.

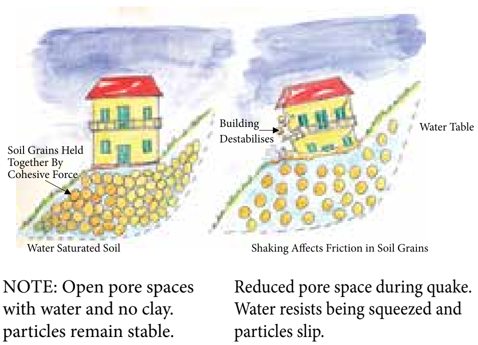


Fig. 2.1: Liquefaction

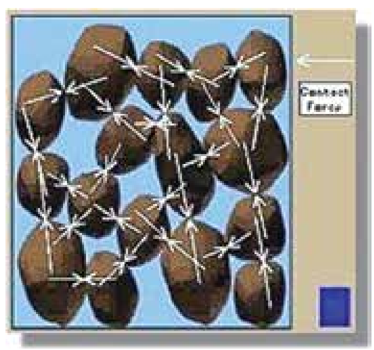


Fig 2.2: Contact forces in soil particles

Reasons

- Loose soil beneath the ground.
- Improper drainage that tends to accumulate water beneath making soil over saturated.

Fig. 2.3: Failure due to liquefaction

Fig. 2.4: Slope failure caused damage to house

2.1.2 Failure of slope occurs

The displacements caused by the waves of earthquake decreases cohesion of the soil and its pressure on soil leading to failures.

2.1.3 Development of tension cracks

Earthquake forces disturb the original structure of the soil, causing tension cracks resulting to landslide.

Fig 2.5: Tension cracks

Fig. 2.6: Lateral spreading
(Source: http://cpwdeablogging.wordpress.com/2012/03/22/slope-failures-and-remedial-measures-for-strategic-highway-construction-in-hilly-terrain/)

2.1.4 Lateral spreading of soil

Massive horizontal movement of soil layers in a direction parallel to the ground slope takes place.

Reasons

- Liquefaction
- Soil characteristics

- Slope instability

2.2 Effects of Precipitation

Excess precipitation leads to intense surface-water flow with pressure and triggers mudslides. Consequently,

- Erosion and mobilisation of loose soil or rock on steep slopes.
- Removal of material from the toe of the slope.
- Saturation by rainwater reducing shear (moving apart) resistance of the slope material.

Fig. 2.7: Loose debris

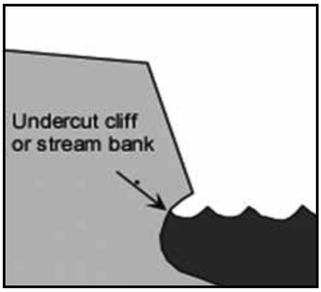


Fig. 2.8: Undercutting

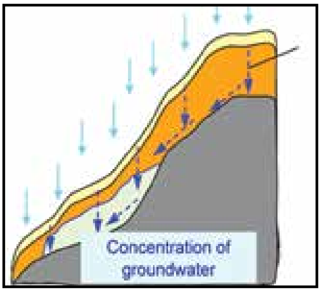


Fig. 2.9: Effect of rainwater on ground

Moreover, increased seepage of water into ground through soil or cracks in the bedrock that results in,

- Groundwater concentration in the bedrock and pressure on rocks making it to fall.
- Increase in pore pressure affecting the soil grains.
- Cracks in bedrock, developed by the impact of gravity or groundwater.
- Freeze and thaw weathering in extreme weather conditions.

Reasons

- Deforestation
- No check over weak material (loose sand/rocks/debris)
- Improper drainage
- Silting of rivers due to improper disposal of muck and other construction materials.

3 MITIGATION OF LANDSLIDES

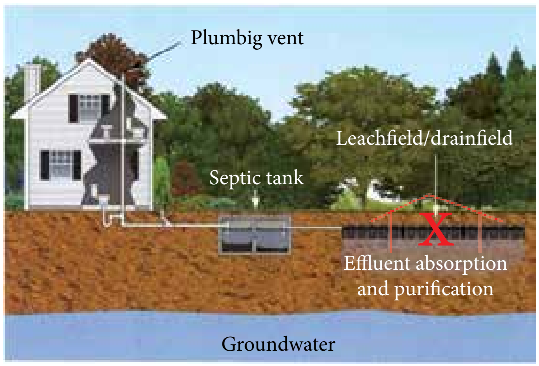
Landslides can be moderated, if proper measures while construction and before taking up a construction are considered.

3.1 Areas where construction should be avoided

Before constructing a house, take into account of following areas where construction shall be avoided.

- Areas where landslides had already taken place.
- Developed hillsides where leach field septic systems/drain fields are used.
- In or at the base of minor drainage hollows.
- At the base or top of an old fill slope and steep cut slope.

(A) Landslide area



(B) Drain field

(C) House built on top of slope

(D) Houses built at toe of slope

Fig. 3.1: Wrong practices of construction (A, B, C and D)

For construction on slopes and on the locations mentioned above, safe construction considerations have to be taken into account to reduce the possibility of failures.

3.2 Check for Slope failure

Before constructing a house on slopes one should always consult a professional, such as a Geotechnical Engineer or a Civil Engineer as they can solve slope instability problems effectively owing to site conditions.

Some ways to reduce slope failures are:

1. Slope Alteration:

   Reduction of slope angle i.e., to make slope gentle from steep or moderately steep as it reduces the weight of the mass tending to slide. It can be done by following:

   - Remove some material from top of the slope and fill the toe of slope to give support to it.

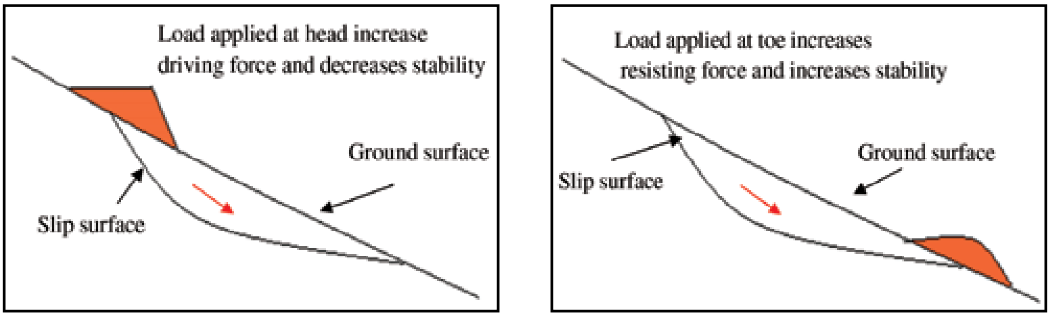


Fig. 3.2: Stabilisation of slope

   - Provide berm below the toe of the slope to increase its stability. It can be constructed by material excavated or any other suitable material like concrete, earth, etc.

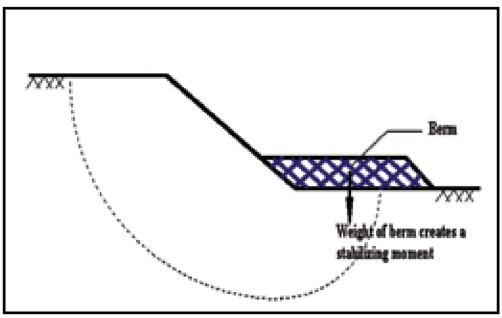


Fig. 3.3: Berm at toe of slope
(Source: http://community.dur.ac.uk/~des0www4/cal/slopes/page6a.htm)

Fig. 3.4: Berm provided at base of home
(Source: http://www.lifeunplugged.net/greenbuilding/earth-berm-and-earth-sheltered-home.aspx)

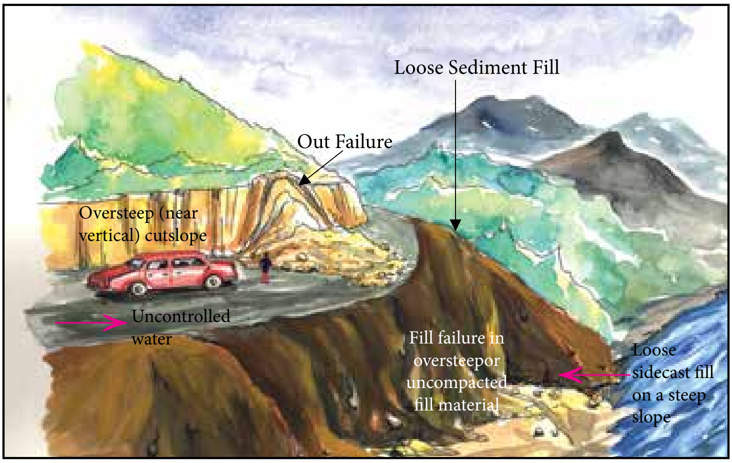


Fig. 3.5: Problems due to slope failure

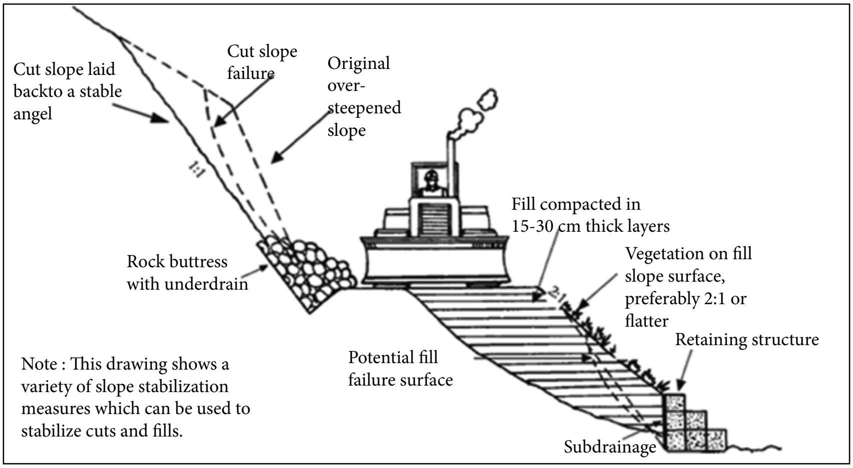


Fig. 3.6: Solutions for slope failure

- Scaling (removal of loose/unstable) blocks/ boulders.

Fig. 3.7: Scaling by hand

Fig. 3.8: Scaling by machine

- Benching: Horizontal benches can be excavated into a slope for most effective protection from steep slope failures as it reduces the height of slope.

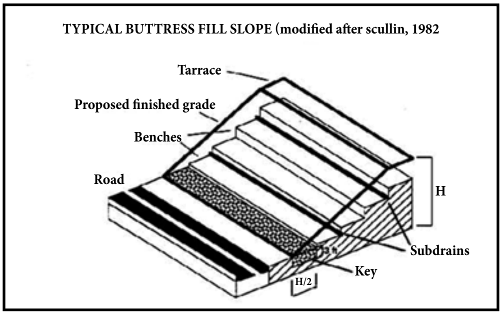


Fig. 3.9: Benching of slopes

- Creating Support for Overhang: Overhang of rocks should be scaled or a wall, creating support for it should be built with suitable strong material else sandbags can be used.

Fig. 3.10: Overhang rock

Table 2.1: Common stable slope ratios for varying soil/rock conditions

Soil Rock Condition	Slope ratio (H:V)
Most rock	¼:1 to ½:1
Very well cemented soils	¼:1 to ½:1
Most in-place soils	¾:1 to 1:1
Very fractured rock	1:1 to 1 ½:1
Loose coarse granular soils	1 ½:1
Heavy clay soils	2:1 to 3:1
Soft clay rich zones or wet seepage areas	2:1 to 3:1
Fills of most soils	1 ½:1 to 2:1

Fills of hard, angular rock	1 1/3:1
Low cuts and fills (<2-3 m height)	2:1 or flatter (for revegetation

(Source: Low Volume Roads BMP, chapter 11)

2. *Stabilisation by Support:* Supporting the sloping material can be helpful in preventing slope failure. It resists the lateral movement of slope and also helps to prevent soil erosion. It can be done by following ways:

   - Retaining WallRetaining wall gives support to slope material by restraining the lateral movement of the material. Soil parameters like bearing capacity, influence the design of retaining wall.

   There are various types of retaining wall based on:

   - Type of construction and mechanics of behaviour.
   - Their design and probable behaviour of construction medium.

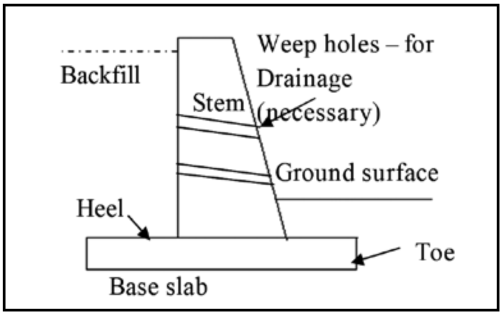


Fig. 3.11: Typical section of retaining wall- Gravity wall

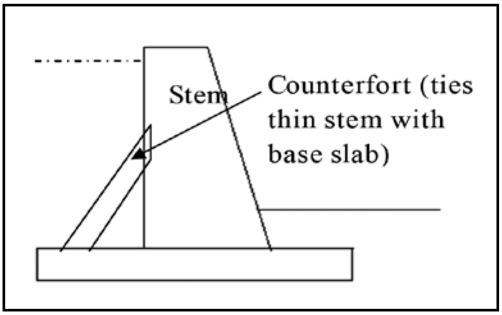


Fig. 3.12: Counterfort retaining wall

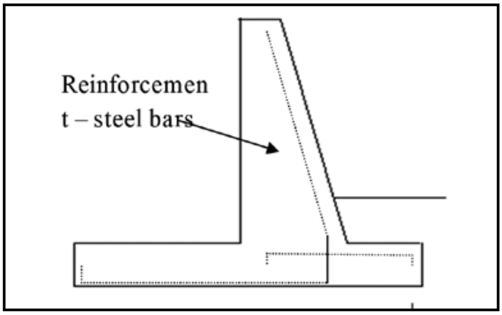


Fig. 3.13: Reinforced concrete wall

Fig. 3.14: Constructed retaining wall for safety of house

- Gravity wall resists lateral pressure through its weight. They are usually constructed by plain concrete or masonry. They are not economical for large heights.
- Counterfort retaining wall stabilises through counter forts–tie backs that ties the stem with base slab. They are spaced across vertical stem at regular interval on backfill side. They are economical for height more than 6 to 8 m.
- Reinforced cement concrete is made of concrete with steel bars placed appropriately after designing thoroughly. They are economical up to height 6-8 meters.
- Cantilever retaining wall is similar to RCC wall with only difference in design- it penetrates to a depth beyond the failure surface and are generally not effective at heights of more than 5 meters. They are used most often in temporary rather than permanent structures.
- Reinforced earth walls are constructed by inserting a thin metal wire or geosynthetic strips to reinforce the soil.

Table 2.2: Different types of retaining wall

Type of Retaining wall	Range of height	Hill slope angle	Top Width	Base width	Foundation depth below the drain	General	Application	Advantage/ Disadvantage
Timber Crib	3-9 m	<30°	2 m	-	0.5-1 m	Timbers of 15 cm diameter with stone rubble well packed behind timber is built. Ecological unacceptable.	Least Durable	Non ductile structure most susceptible to damage caused by earthquake
Dry stone	1-6 m	<35°	0.6-1.0 m	0.5-0.7 H*	0.5 m	Stones are set along foundation bed. Long bond, hand packed stones shall be used in backfill.		
Banded Dry stone masonry	6-8 m	20°	0.6-1.0 m	0.6-0.65 H*	0.5-1 m	Cement masonry bands of 50 cm thickness at a distance of 3 m are used	Most durable	
Cement masonry	1-10 m	35°-60 °	0.5-1.0 m	0.5-0.65 H*	0.5-1 m	Weep holes of 15X 15 cm size at 1-2 m distance are built. 50 cm rubble backing for drainage is provided.		

Gabion	Low	l-6 m	35°-60 °	1 m	0.6-0.75 H*	0.5 m	Stones used in gabion wall shall be hand packed. Stone shape preferably should be blocky. No weathered stone to be used. Compacted granular back fill in layers shall be used.	Can take differen-tial settlem-ent and slope movem-ent	Very flexible structures
	High	6-10 m	35°-60 °	l-2 m	0.55-0.65H*	1 m			
Retaining earth		3-25 m	<35°	4 m or 0.7-0.8 m	4 m or 0.7-0.8 H*	0.5 m	Granular back fill is preferred. Drainage layer shall be provided for seepage problems.	Huge potential, used more as stable reinforced fill platform for road rather than preventive method of slope support.	

(Source: IS 14558 (Part-1)

IMPORTANT POINT:

Material behind the wall should be well drained.

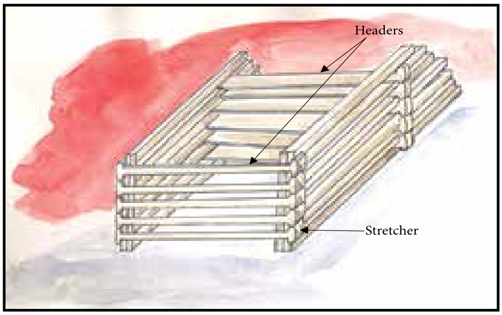


Fig. 3.15: Section of timber crib

Fig. 3.16: Constructed timber crib wall

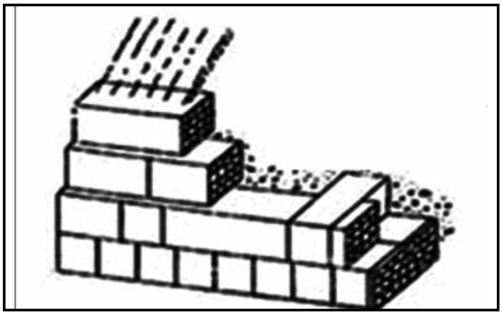


Fig.3.17: Gabion wall

Fig. 3.18: Constructed Gabion wall

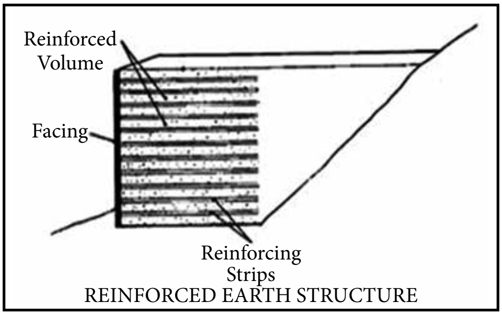


Fig. 3.19: Reinforced earth wall

Fig. 3.20: Dry stone wall

Fig. 3.21: Reinforcement placed for construction of wall

Other types of retaining walls, that can be used, are:

- Steel bin wall: steel bin wall is formed from corrugated galvanized steel components bolted together to form a box and then filled with earth. It is a type of gravity wall.

Fig. 3.22: Steel bin wall construction

Fig. 3.23: Precast concrete blocks

Fig.3.24: Wall constructed with sand bags

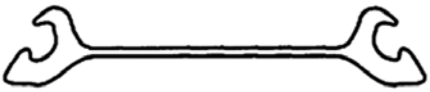
- Sandbag retaining wall: Sandbags can also be used as retaining wall but for temporary basis or for short time period during rainfall. They tend to get eroded with time and are sensitive to outer climate conditions.

- Precast concrete wall: Retaining wall can also be constructed with precast concrete blocks. It is economical and durable. It provides good drainage and doesn't need skilled labour for its erection.
- Sheet piles: Sheet piles made of steel or timber, form a continuous wall or bulkhead that retains earth, provided the depth of driving does not exceed 3m. They can be extracted and re-used if required.

  Even reinforced cement concrete sheet piles can be used, but are suitable for fine sand.

  Sheet piles can also be anchored in soil for more lateral resistance.

Different shapes of sheet piles are:



Straight sheet pile

Arch web sheet pile

Shallow arch sheet pile

Z- shaped sheet pile

Fig. 3.25: Different types of sheet pile

Fig. 3.26: Sheet piles

Restraining structures using empty bitumen drum:

- It is a temporary low cost restraining structure up to a maximum height of 3 meters.
- The top and bottom covers of the bitumen drum are removed and the cylindrical shell is utilised. These are arranged in two rows one behind the other.
- The drums are interconnected both vertically and horizontally by mild steel plates, rods and bolts.
- The drum wall is suitably connected at the base and backfilled for preventing sliding and tilting. Also, drums are filled with debris and boulders to give weight and stability.

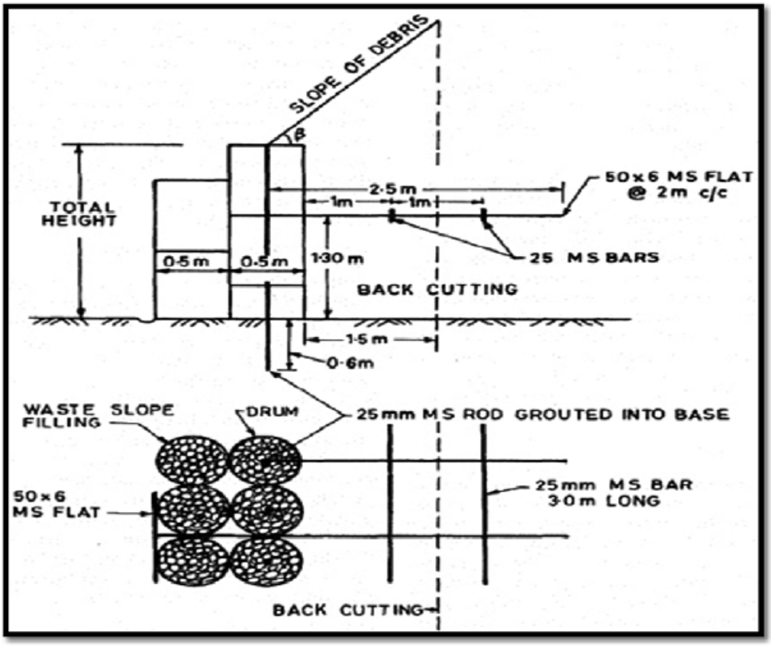


Fig. 3.27: Plan of empty bitumen drum
(Source: CBRI, Roorkee)

- Ground Inclusions: A ground inclusion is a metal bar that is driven into strong bedrock (rock that is not highly fractured or broken up) to provide a stable foundation for structures such as retaining walls and piles and also to strengthen rocks with cracks.

There are three types of ground inclusions.

- Ground anchors: They provide vertical and lateral support for engineered structures and natural slopes. They are used to tie-back retaining walls to prevent failures due to rotational loading and also to strengthen fissured material like rocks. It is provided according to the length required.

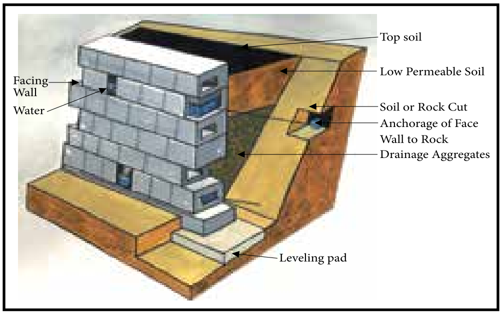


Fig. 3.28: Ground anchors

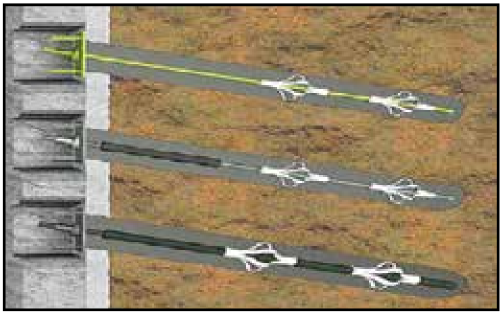


Fig. 3.29: Soil nailing
(Source: http://www.p3planningengineer.com/productivity/soil%20improvement/soil%20nail/soil%20nail.htm)

- Soil nails: In soil nailing, metal bars or rods are driven into soil to strengthen the soil mass. They are attached to concrete facing located at the surface of the structure. It prevents erosion of the surface material surrounding the soil nails but do not provide structural support as such.
- Rock bolts: Rock bolting is a method of securing or strengthening closely jointed or highly fissured rocks in cut slopes by inserting and firmly anchoring a steel bar in pre drilled holes that range in length from less than one meter to about 12 meters and are attached to some type of facing.

Fig. 3.30: Rock anchors

IMPORTANT POINTS

- Metal inclusions are to be protected from corrosion by a sealant or grout, otherwise due to groundwater, breakdown of inclusions would accelerate.
- The effects of creep on anchored system must be considered while designing.
- Construction above the anchors should be limited as excavation would undermine the stability of any anchor present.

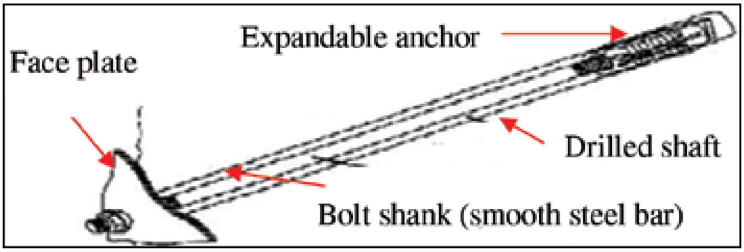


Fig. 3.31: Typical anchor

- Cable, wire- mesh, fencing: They are simple, low-cost methods for protecting slope.

  Wire mesh (closely spaced interwoven wires) can be used to prevent smaller rocks, less than 0.75 metres (2.4 feet) in size, from falling. (The standard mesh is double-twisted gabion wire mesh or a heavy gage metal chain link). The mesh is either loosely draped over a uniform rock face or bolted where the cliff face is irregular and the mesh cannot make close contact with the rock.

Fig. 3.32: Wire mesh

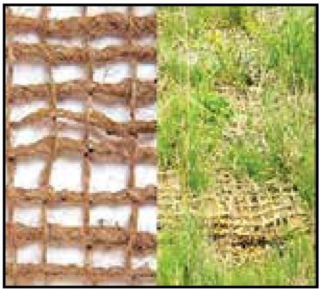


Fig. 3.33: Jute netting

Fig. 3.34: Plastic mesh
(Source:http://www.huataowiremesh.com/product/activeprotection-system.html)

- Plastic mesh: Plastic mesh is a reinforcement material of plastic polymer stretched to form a lightweight, high-tensile-strength grid. The grid acts similar to reinforcing mesh in concrete, adding strength to the shear strength of the soil.
- Reinforced earth: Reinforced earth is a construction system made up of frictional backfill material reinforced with flexible strips and covered with facing elements.

  It is constructed by layering soil with either metal strips or geosynthetic materials that are brought into tension first for resisting horizontal deflection.

  Each strip is about 50 – 100mm wide and several metres in length. The thickness is up to 9 mm.

  The reinforcement connects to the facing element and extends back into backfill zone. The friction developed in reinforcement retains the facing element. Reinforcement is placed before backfilling with granular soil. It is continued till required height of wall.

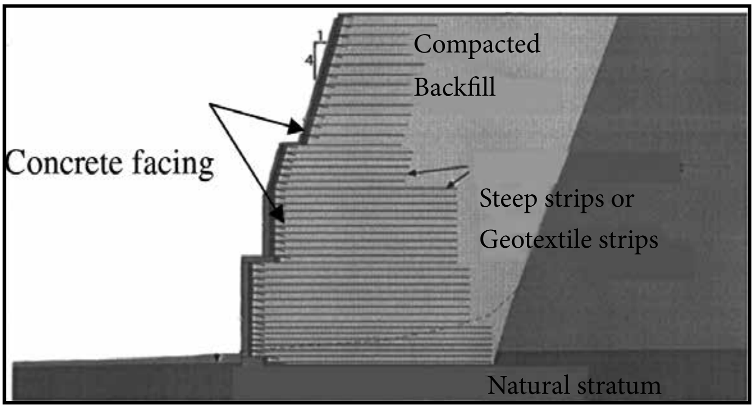


Fig. 3.35: Reinforced earth section

- Check for freeze and thaw weathering: Seal tension cracks in rocks through grouting, to rule out possibility of water percolation through cracks and to eliminate weak surfaces.

3.2.1 Measures for Stabilization

- Stability problems most often occur when the house is built over soft soils such as low strength clays, silts, or peats.
- Determination of soil properties like stiffness, compressibility,

cohesive forces and ground water that affect its strength should be done by field and laboratory testing by experts.

3.2.1.1 Types of soils

There are mainly two types of soils:

- Cohesive soil: Cohesive soils are soils that adsorbs water and particle attraction act such that it deforms plastically i.e., undergo deformation without cracking or fracturing at varying water contents, that is due to presence of clay minerals in soils.

  Cohesive soils include clays and plastic silts.

- Non cohesive soils: Soils that don't show plastic characteristics and have bulky grains are non-cohesive soils. They deform through friction.

  It includes silts, sand and gravel.

3.2.1.2 Soil Improvement Techniques

- Soil improvement means making the soil stable by altering some of its properties so that it can be proved safe for construction.
- Cohesive soils such as soft clay have large voids and high water content, which reduce permeability, pore water pressure and compressibility of soil, thereby increasing its load carrying capacity (shear strength of soil).

Methods to be followed are:

1. By compaction: Compaction means pressing the soil particles close to each other by mechanical methods. Air during compaction is expelled from void spaces and its mass density increases. Thus, it improves soil engineering properties. It can be done by following:
   - Vibroflotation: Vibroflot consists of a cylindrical tube, about 2 to 3 metre long and 300 to 500 mm in diameter, fitted with water jets at top and bottom. It contains rotating eccentric mass that develops horizontal vibratory motion causing the grain structure to collapse, thereby compacting the soil surrounding the probe.
   - Terra probe method: Terra probe method is similar to vibroflotation but faster.

     It consists of an open ended pipe provided with vibratory pile driver that gives vertical vibrations and soil within and around terra probe gets densified.

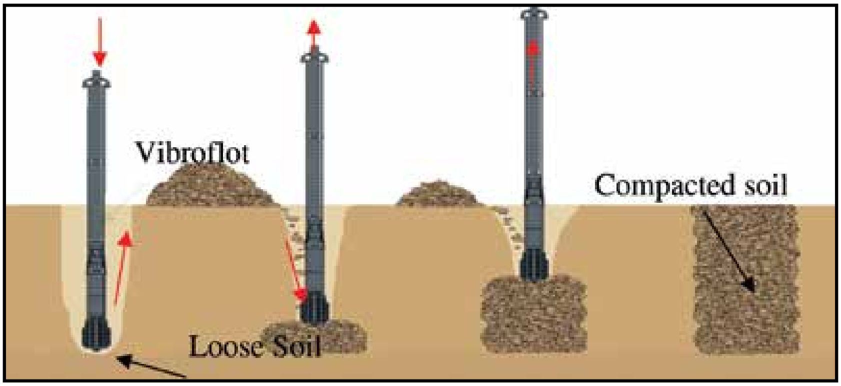


Fig. 3. 36: Explanation of mechanism of vibroflotation

- Dynamic compaction: Dynamic compaction is done by dropping a heavy weight of steel or concrete of mass 2 to 50 mg in a grid pattern from height of 7 to 35 m. It densifies loose sandy deposits. It is an economical way of compacting soil.
- Compaction by blast: The shock waves and vibrations produced by explosives buried in ground densify the cohesionless soil.
- Compaction by rollers: Smooth wheel rollers can be used to compact cohesion less soil with small thickness and for thick layer soils, vibratory rollers are used.

Fig. 3.37: Dynamic compaction

Fig. 3.38: Roller
(source: http://www.indiamart.com/brijenterprises/road-construction-equipmentrenting-hiring-service.html)

Cohesive soils can be compacted by Sheep foot rollers.

Tampers and Pneumatic tyred rollers can be used to compact any type of soil.

- Compaction Piles: Installing compaction piles densify the soil through vibration produced during driving the pile in ground. It is removed afterwards and hole created is backfilled with soil. Compaction piles are made with prestressed concrete or timber. Its length should be according to depth of loose soil.

Fig. 3.39: Mechanism of driving pile
(Source: http://theconstructor.org/geotechnical/driven-precast-concrete-piles/7092)

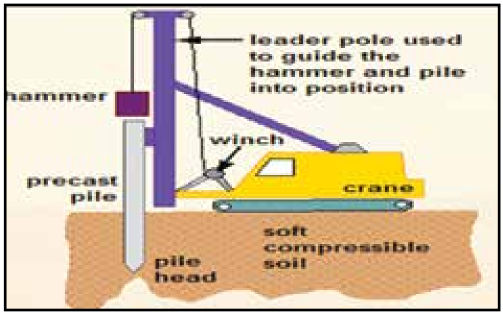


Fig. 3.40: Driving pile through drop hammer
(Source: http://koper.pro/?qlang=plugins/cat/item/cid/11/tehn/19/id/47&goto=ru)

2. By mixing
   - Soil can be improved by mixing two or more types of natural soils to obtain a composite material of better strength. Soils with coarse particles are usually added.
   - Even, cement can be mixed with soil with help of water and compacted to get a strong material, usually called soil-cement.
   - Soil with weak properties can be replaced with better mix of soil.
3. By lime
   - Soil can be improved by adding lime to soil. Lime reacts with soil and decreases its plasticity, making it more workable and increases its strength.
   - Amount of lime varies between 2 to 10 percent of soil.

- 2 to 5 percent lime is used for clay gravel material, having less than 50 percent of silt-clay fraction.
- 5 to 10 percent lime for soils having more than 50 percent of silt-clay fraction.
- For soils having size intermediate, 3 to 7 percent of soil is fine.
- About 10 percent for heavy clays used as bases and sub bases for roads or foundations.
- If sandy soil is to be stabilised then clay, fly ash or other pozzolanic materials have to be added in addition to lime.

4. By chemical stabilization

   Soil can be stabilised by adding different chemicals like:

   - Calcium chloride – Quantity required is about (½) percent of weight of soil.
   - Sodium chloride – Quantity required is about 1% of soil weight.
   - Sodium silicate - Quantity required varies between 0.1 to 0.2 percent of weight of soil.
   - Polymers- Resins are natural polymers and Calcium acrylate is a commonly used synthetic polymer to stabilise soils.
   - Chrome lignin- It is a by-product obtained during manufacture of paper from wood. When added to soil, it reacts to bond the soil particles and its quantity required varies from 5 to 20 percent of weight of soil.

   It improves the characteristics of soil.

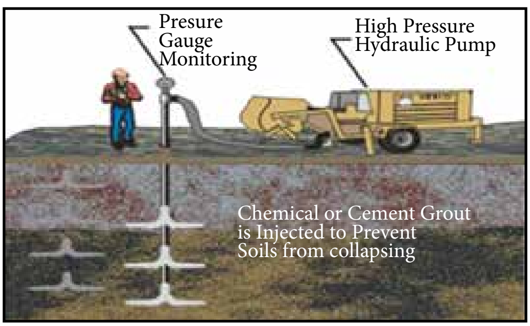


Fig. 3.41: Grouting done by machine
(Source:http://www.geotechnical.com/ulti mo/foundation-repair.htm)

- It is the most expensive type of stabilisation, but setting time and curing time of cement can be controlled easily.
- Other chemicals like phosphoric acid, sodium hexa-metaphosphate etc. can also be used to increase soil density.

5. By bitumen
   - Sandy soils having little or no fines can be stabilised by adding bitumen to the soil and asphalt as a binder with gasoline as a solvent. Asphalts are materials in which, primary components are natural or refined petroleum bitumen.
   - The amount of bitumen required generally varies between 4 to 7 percent by weight, whereas actual amount is determined by trial.
6. By Grouting
   - Grout is cement, silicate, or acrylamide based slurry, that is poured or injected with pressure into soil, and thereby fill, seal, or compact the surrounding soil. It is suitable for soils with very high permeability.
   - It is also an expensive method.
   - It is effective for rocks with fissures and best to improve soils that cannot be disturbed.
   - Grout can also be prepared by chrome
   - Lignin or polymers or bitumen or clay.
7. By geosynthetic/geogrids
   - Geosynthetics are porous, flexible, man-made fabrics such as polyethylene, polyester, nylon that reinforces and increase the stability of structures such as earth fills, and thereby allow steeper cut slopes and less grading in hillside terrain.
   - Long term durability is important when geosynthetics are used in slope stability since deteriorated fabrics may cease to function properly.
   - Geotextile sheets are manufactured in different thicknesses ranging from 10 to 300 mils or .254 mm to 7.62mm(1 mil= 0.0254 mm). The width can be up to 10 m and are available in rolls in market.
8. Sand drains
   - A sand drain is constructed by driving a casing of steel into the

ground and then filling the casing with suitable graded (suitable) sand.

- The casing is then removed, leaving sand in ground.
- A sand blanket is placed over the top of all sand drains to connect them.
- On sand blanket, surcharge load is provided that consolidates the soil.
- Radius of sand drain is kept 0.2 to 0.3 metre, spacing of sand drain is kept around 2 to 5 metre and depth in embankment is kept around 3 to 35 metre.
- A sand blanket with thickness of 0.6 metre to 1 metre is placed over top to connect them.

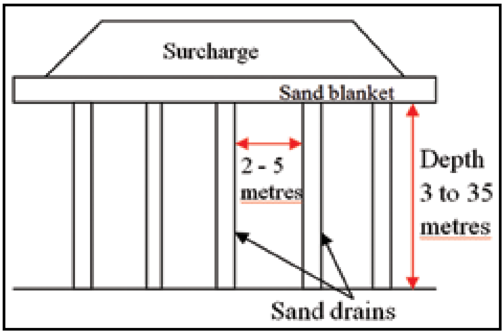


Fig. 3.42: Sand drain

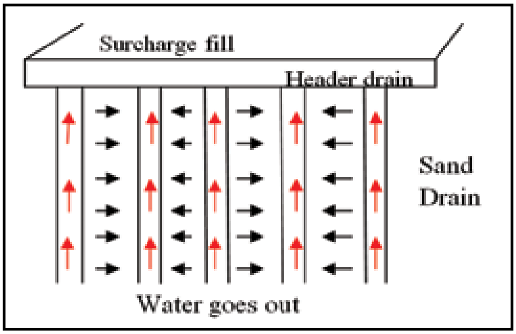


Fig. 3.43: Wick drain

9. Wick drains
   - Sand drains being expensive, wick drains are preferred over them.
   - They are prefabricated vertical drains consisting of corrugated or fluted plastic ribbons covered by geosynthetic membranes.
   - At the top of wick drain, header drain is provided to discharge the pore water.
   - The wick drains are usually of the shape of a strip 100 mm wide and 5 mm thick.
10. Stone columns
    - Stone columns are constructed by making holes in the deposit by vibroflot and then filling these holes with gravel (or small stones) of size 6 to 40 mm and densifying it.

- They act as vertical drains and increases consolidation.
- The spacing of stone columns is generally between 1.5 to 3 metre centre to centre and their diameter is usually 0.5 to 0.75 metre.
- They are not effective for thick deposits of highly organic clays and silts.

3.3 Check for Soil Erosion:

Instability increases with increasing erosion as it exposes the soil, soil being sensitive to outer forces and reduces its strength resisting deformation.

- **By Vegetation:** It is a bio-engineering method.

a) Seeding: Seeding with grasses and legumes reduces surface erosion.

- There are two basic types of seeding:

  1. **Dry Seeding:** Dry seeding is done with rotary disk and air-blown seeders. These methods are less costly than hydraulic seeding, but are limited to rough soil surfaces and gentler slopes. Rotary disk seeders spread seed and fertilizer by centrifugal force. Seeder is the air-blown seeders use air to blow or shoot seed and fertilizer at a distance of 5 to 8 meters (15 to 24 feet). Equipment can be adapted for motorized vehicles.
  2. **Hydraulic seeding or Hydro seeding:** This type of seeding is the application of seed in a water slurry that contains fertilizer, soil binder, and (or) mulch. The system requires a mixing tank with mechanical hydraulic agitation and volume pumping capacity. Hydraulic seeding is effective for seeding slopes in the ratio 1:1 and steeper, where tacking of the seed to the slope is necessary.

Disadvantages:

- May produce vegetation that requires irrigation and maintenance.
- Depends heavily on the season and rainfall rate for success.
- Requires protection from heavy use, once seeded.

Before seeding:

- Control surface drainage
- Remove cut bank overhangs
- Reduce slope angle

Fig. 3.44: Vegetated slope with drainage underneath

- Provide benching
- Planting native mix of shrubs, trees and plants, adds vegetative cover and stronger root systems and help, to filter and absorb some of the water.
- Suitability of seeds depends on soil type, climatic conditions, spe-cies compatibility, and species replacement.

  ** One of the most promising types of plants is Vetiver, a type of grass that works very well to stabilize slopes against erosion in many different environments.

b) **By Turfing/Sodding**

- Turfing is the direct application of grass with developed roots onto the slope surface.
- The relatively matured grass will grow easier and extend its root into the soil to strengthen the overall surface.
- Can be used for site activities within a shorter time than can seeded vegetation.
- Can be placed at any time of the year as long as moisture conditions in the soil are favorable.

Disadvantages:

- May require continued irrigation if the sod is placed during dry seasons or on sandy soils.
- Purchase and installation costs are higher than for seeding.

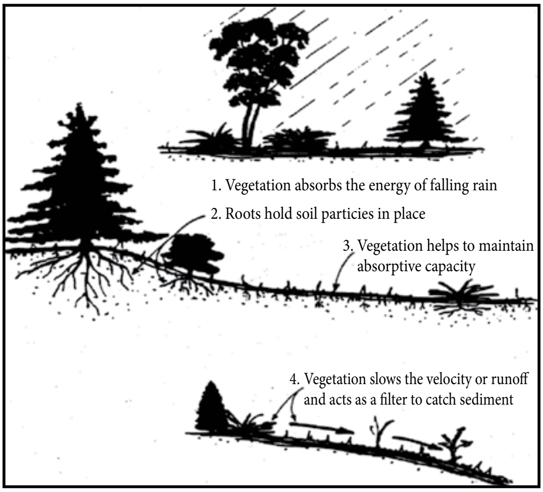


Fig. 3.45: Advantages of vegetation

c) Mulching:

Mulch is a non-living material spread over the soil surface to provide protection from surface erosion by rain and retention of soil moisture. Various types of mulches are straw, grass fibers, wood fibers, seaweed, hay, gravel and paper products.

Mulching is often used alone in areas where temporary seeding cannot be used because of the season or climate.

Mulching can provide immediate, effective, and inexpensive erosion control.

Asphalt mulch treatment

An asphalt emulsion (mulch) is a mixture of dark bituminous pitch with sand or gravel of a suitable grade is spread by a sprayer after dibbling seeds in the soil. The asphaltic film gradually disintegrates and its place is taken by a carpet of green vegetation.

Disadvantages:

- Some mulch materials such as wood chips may absorb nutrients necessary for plant growth, so it should be chosen carefully.
- It may delay germination of some seeds because cover reduces the soil surface temperature.
- Mulch can be easily blown or washed away by runoff if not secured.
- Bally benching.

Wooden ballies (posts) of 120 to 150 mm dia and 2.0 to 2.7 m long are vertically driven in rows into the slope.

They are tied with three tiers of horizontal runners long nails or braced with galvanised wires.

Finally the uphill side of gullies/chutes is backfilled with boulders to avoid erosion.

d) Fascines/brush wattles

Fascines can be best described as a rope-shaped bundle of live cuttings, lashed together with twine.

The resulting root systems work well to secure soils and to hold the fascine in place.

They are simple and effective, require little time to build and can be installed with little site disturbance.

Fascines can also be used as drains to conduct runoff or bank seeps.

e) By Geotextiles/ geosynthetic

Some geotextiles are biodegradable materials such as mulch matting and netting.

- Mulch mattings are materials (jute or other wood fibers) that have been formed into sheets of mulch are more stable than normal mulch.
- Netting is typically made from jute, other wood fiber, plastic, paper, or cotton and can be used to hold the mulching and matting to the ground.

Netting can also be used alone to stabilise soils while the plants are growing; however, it does not retain moisture or temperature well.

Effective netting and matting require firm, continuous contact between the materials and the soil. If there is no contact, the material will not hold the soil and erosion will occur underneath the material.

It offers convenience to the installer.

Disadvantages:

- Many synthetic geo-textiles are sensitive to light and must be protected prior to installation
- If the fabric is not properly selected, designed, or installed, the effectiveness may be reduced drastically.

f) By Dentition

Exposed soft material in a rock face can be trimmed back.

The resulting slot be filled with filter material and protected by masonry or concrete to prevent erosion.

g) By chemical stabilization

Materials made of vinyl, asphalt, or rubber is sprayed onto the surface of the soil to hold the soil in place and protect against erosion from storm water runoff and wind.

Many of the products used for chemical stabilisation are human-made.

It is effective in stabilising areas where plants will not grow.

Disadvantages:

- Is usually more expensive than vegetative cover.
- Can create impervious surfaces (where water cannot get through), that may in turn increases the amount and speed of storm water runoff.
- May cause harmful effects on water quality if not used correctly.

h) By preventing wildfire

- Wildfire leads to loss of soil nutrients and also decreases forces within soil thus making it vulnerable to erosion.

So one should take precautions to prevent wildfire:

- Never leave a campfire unattended. Completely extinguish the fire by dousing it with water and stirring the ashes until cold before sleeping or leaving the campsite.
- Prepare your campfire by removing all leaves, twigs and other flammable material from the area.
- When camping, take care when using and fueling lanterns, stoves, and heaters. Make sure lighting and heating devices are cool before refueling. Avoid spilling flammable liquids and store fuel away from appliances.
- Do not discard cigarettes, matches, and smoking materials from moving vehicles, or anywhere on park grounds. Be certain to completely extinguish cigarettes before disposing of them.
- Place a firebreak like materials that don't catch fire and fence the area to cut the fire from expanding.

- Avoid backyard burning in windy conditions, and keep a shovel, water, and fire retardant nearby to keep fires in check. Remove all flammable material from yard when burning.
- Covering the slope with an impermeable membrane

  Impermeable membranes are flexible sheets of synthetic material that don't let water to infiltrate into ground.

  They are either glued to ground or anchored into ground at places.

3.3.1 Stream Bank Stabilisation

If the construction is done on the slope adjacent to river, then stream bank erosion can take place making the slope unstable with time. Thereupon, stream bank stabilisation is used to prevent bank erosion from high velocities and quantities of storm water runoff. Typical methods include the following:

1. Riprap

   Large angular stones are placed along the stream bank or lake.

2. Gabion

   Rock-filled wire cages are used to create a new stream bank.

3. Reinforced concrete

   Concrete bulkheads and retaining walls replace natural stream banks and create a non-erosive surface which helps in preventing erosion of stream banks.

4. Log cribbing

   It is Retaining walls built of logs to anchor the soils against erosive forces. It is usually built on the outside of stream bends

5. Grid pavers

   Precast or poured-in-place concrete units are placed along stream banks to stabilize the stream bank and create open spaces where vegetation can be established

6. Asphalt

   Asphalt paving is placed along the natural stream bank to create a non-erosive surface.

   Stream bank stabilisation is used where vegetative stabilisation practices are not practical and where the stream banks are subject to heavy erosion from increased flows or disturbance during construction.

- Stabilisation should occur before any land development in the watershed area.
- Stabilisation can also be retrofitted when erosion of a stream bank occurs.

Disadvantages:

- Does not provide the water quality or aesthetic benefits that vegetative practices can.
- Should be designed by qualified professional engineers, that may increase project costs.
- May be expensive (materials costs).
- May require additional permits for structure.
- May alter stream dynamics that cause changes in the channel downstream.
- May cause negative impacts to wildlife habitats.

3.4 Check for Rising Ground Water Levels

For slope and soil stability, drainage plays an important role. It helps in reducing the seepage forces and also keeps a check on ground water as increasing ground water leads pressure on building that may lead to failure due to increased forces.

Proper measures should be taken to provide drainage before doing construction.

- Things to keep in mind:

  Minimise surface irrigation - Water or irrigate with care; do not soak lawn or garden areas located on or near steep slopes. Select plants that do not require deep or intensive watering.

  Keep a check and repair leaks in plumbing, irrigation pipes, drains, gutters and swimming pools.

  Divert flows from the slide area.

  Avoid placing fill, including yard clippings, excavated material, sand and soil, at the top of steep slopes or along pre-existing drainage channels.

  Provide surface drainage at top of cut and fill.

  Use flexible pipelines with access for maintenance.

3.4.1 Control of Surface Water: Controlling water on roads and on hill slopes.

a) Catch water or interceptor drains:

- A ditch cut across the fall of the land, typically just above the level of low-lying, level ground to collect and remove surface water as it flows across the impermeable layer.
- To divert the water from hill slope, catch water drains should be located very carefully. They shall be lined and properly maintained.
- Gradient of 1 in 50 to 1 in 33 should be provided to avoid high water velocity and possible wash out.
- Water from catch water drain shall be diverted into a chute or natural hillside

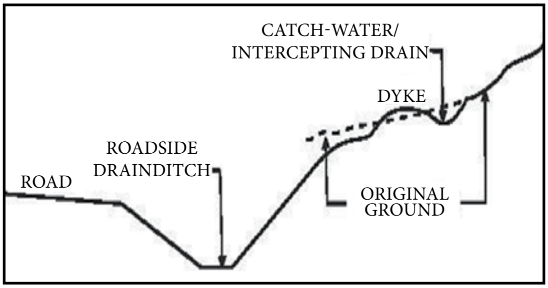


Fig. 3.46: Section of intercepting drain on hill slope
(Source: IS code 14680)

Fig. 3.47: Intercepting drain
(Source: http://hkbus.wikia.com/i/%E6%AA%94%E6%A1%88:Cheung_Sha_Catchwater_4.JPG)

b) Roadside drains:

- Roadside drains are provided on the roadside at the foot of the hill slope to drain out water from the road surface and water from portion of hill slope below the catch water drains.

Fig. 3.48: Roadside drain
(Source: www.autospec.co.za)

- They are constructed of dry rubble stone masonry with semi-circular saucer, rectangular, trapezoidal angle drain and kerb and channel drain in sections.
- Angle or kerb and channel drains are suitable where road width is restricted and they do not get easily damaged.
- The slope of water shall be 1:20 to 1:25 so that it can flow at self- cleansing velocity.

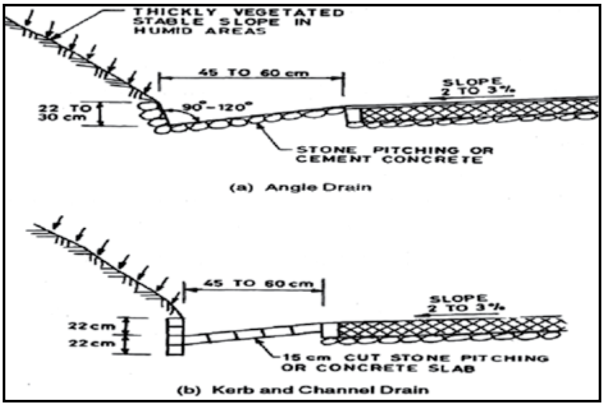


Fig. 3.49: Section representing kerb and angle drain
(Source: IS code 14680)

c) Cross drains:

- They shall be provided at intervals of 4 to 6 km depending on nature of terrain.
- They shall be provided at every point of natural nallah and water crossing.
- The cross drainage structures are:

i. Culverts:

- A structure built to allow water flow under a road, railroad, trail, or similar obstruction and is surrounded by soil. A culvert may be made from a pipe, reinforced concrete or other material.
- A catch pit is provided at the mouth of the culvert towards the hill slope.
- The minimum width of 0.9 m and height 1.5 m is kept for cleaning them before and after the rainy season.
- Adequate protective works are required at the discharge point towards valley side, that shall preferably be stepped toe walls to dissipate energy of water.

Different types of culverts are:

- *Arch culvert:* Arch culvert consists of abutments, wing walls, arch, parapets and the foundation made of stone masonry or concrete. Floor and curtain wall shall be provided to avoid erosion of foundation of soil.
- *Slab culvert:* It consists of RCC slab with or without beams or a stone slab or steel girders to cover the span across abutments and piers.
- *Pipe culvert:* They are provided when discharge of stream is smaller or sufficient height of bank is not available. Usually, one or more RCC pipes of 0.50 m or 0.90 m diameter are placed side by side. Walls are provided for easy approach of water. The gradient should not be flatter than 1 in 30.

Fig. 3.50: Arch culvert

Fig. 3.51: Slab culvert

Fig. 3.52: Pipe culvert

ii. Scupper: The water collected through side drains or nallah is discharged to the valley side through a small cross drainage structure 0.9 top and 1.0 m wide made of random rubble dry masonry abutments and is economical. Retaining walls are provided at both ends of scupper.

iii. Causeways: Solid or vented causeways are provided at the places where discharge is large with shallow depth, less velocity and debris flow is not defined.

There are two types of causeways:

- *Low level causeway:* Banks that remain dry for most part of the year, are cut down at an easy slope. Stream or river having sandy beds, are generally provided with the stone paving on substantial bed of concrete with upstream and downstream out off walls to prevent possible scour.

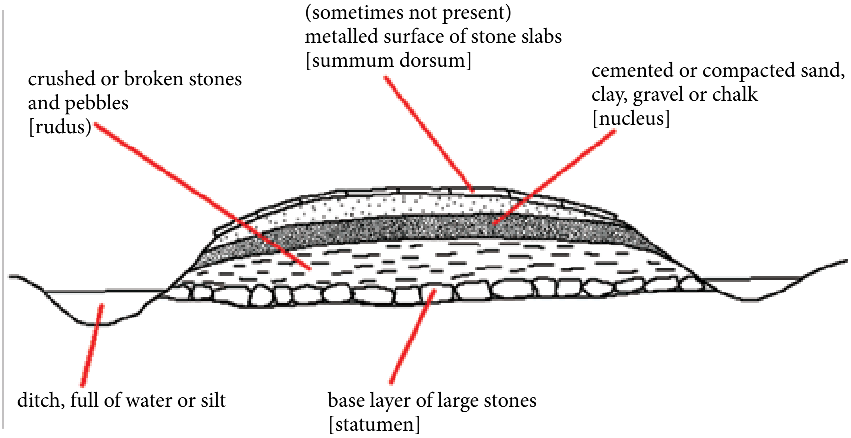


Fig. 3.53: Section of causeway
(Source: Wikipedia)

- *High level causeway:* It is submersible road bridge designed to be overtopped in flood. Its formation level is fixed such as not to cause interruption to traffic during flood for more than 12 hours at a time.

Fig. 3. 54: Constructed causeway

Fig. 3.55: Rice straw wattle drains
(Source: www.th.gov.bc.ca440)

d) Straw wattles and straw bales

- Straw wattles, also known as straw worms, bio-logs, straw noodles, or straw tubes, are manufactured cylinders of compressed, weed-free straw (wheat or rice).
- They are 20 to 30 centimeters in diameter and 7 to 9 meters long encased in jute, nylon, or other photodegradable materials.
- They are installed in a shallow trench forming a continuous barrier along the contour (across the slope) to intercept water running down a slope.
- Their effect diminishes greatly on slopes steeper than 50 percent.
- Soils should not be less than 8 inches.

3.4.2 Control of sub-surface water that infiltrates into ground

a) Horizontal drains

- Horizontal drains are 50 mm in diameter perforated/slotted rigid PVC pipes.
- Generally, the upper two-third portion of the pipe section is perforated/slotted
- The pipes are installed in pre-drilled boreholes at a negative gradient of 5 to 15 degrees to the horizontal into a hill or an embankment.
- To avoid the risk of PVC pipes sliding out or being withdrawn, a check valve – that controls flow of water is fitted permanently on the first length of the PVC pipe before introducing into-the pre-drilled hole.

(Source: www.bca.gov.sg)

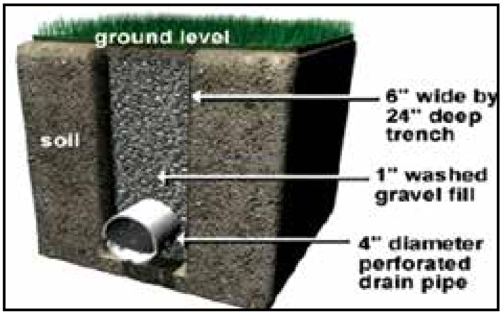
(Source: www.newslincolncounty.com)

Fig. 3.56: Horizontal drains

b) Deep trench drains/ditches:

- A trench is a deep and narrow hole, or ditch, in the ground.
- Deep trench drains are used where water can be intercepted at depths less than 5 to 8 m.
- Filter-fabric covered trench drains consist of a permeable gravel core, surrounded by a filter fabric to prevent clogging.

(Source: www.ideasget.com)



(Source: www.trenchdrainblog.com)

Fig. 3.57: Trench drains

c) Weep holes

Weep holes are the gaps left between some bricks in external masonry walls or retaining wall for drainage purposes.

Fig. 3.58: Weep holes in wall
(Source: http://construdeia.com/furo-na-parede/)

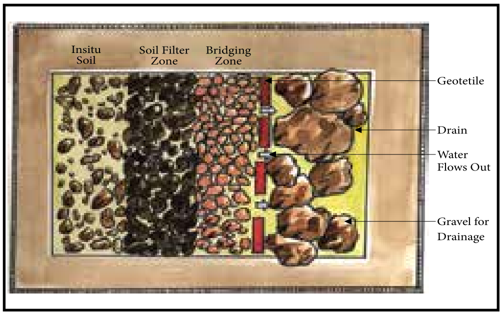


Fig. 3.59: Geotextile as filter membrane
(Source:http://autospec.co.za/productmedia/kaytech/geotextile_fdg/geotext_fdg_overview.htm)

d) Filter membranes

- Proper filters have to be provided around the drains so as to prevent soil entering into pipe, thereby preventing clogging of drains.
- The particle size of the filter should be adequate so as to hold the protected material in place.
- Geotextiles can be used as filters.

e) Geotextile drains

- Geotextiles can also be used as drains because of their pervious nature and high water carrying capacity.
- Geotextiles are installed in a soil with a proper opening at one end.

3.4.3 Special Provision for Storm Water Run-off

- Drainage check for storm water run-off over slope that is high in volume and pressure and destabilizes slope is very important. Also, it brings a lot of debris with it that can clog the drains, so proper measures to carry it off is very important especially at the time of heavy rains.

a) Earth dike

- An earth dike is a ridge or, ridge and channel combination used to protect work areas from upslope runoff and to divert sediment-laden water to appropriate traps or stable outlets.

- The dike consists of compacted soil and stone, riprap, or vegetation to stabilise the channel.
- Can be constructed from materials and equipment that are typically already present on a construction site
- Frequent inspection and maintenance is required.

b) Drainage swale

- A drainage swale is a channel with a lining of vegetation, riprap, asphalt, concrete, or other material.
- It is constructed by excavating a channel and applying the appropriate stabilisation.
- Use is restricted to areas with relatively flat slopes.

Fig. 3.60: Drainage swale
(Source: http://www.panoramio.com/photo/11818039)

Fig. 3.61: Interceptor dike
(Source: http://www.calpaclab.com/silt-dike-runoff-protection-erosion-control-barrier/ut-9712)

c) Interceptor dikes and swales

- Interceptor dikes (ridges of compacted soil) and swales (excavated depressions) are used to keep upslope runoff from crossing areas where there is a high risk of erosion.
- They reduce the amount and speed of flow and then guide it to a stabilized outfall (point of discharge) or sediment trapping area.
- Runoff is channeled away from locations where there is a high risk of erosion by placing a diversion dike or swale at the top of a sloping disturbed area.
- May cause problems to vegetation growth if water flow is too fast.
- If constructed improperly, can cause erosion and sediment transport since flows are concentrated.

d) Silt fence

- A silt fence, also called a "filter fence," is a temporary measure for sedimentation control. It consists of posts with filter fabric stretched across the posts and sometimes with a wire support fence.
- A silt fence is used in small drainage areas to detain sediment.
- These fences are most effective where there is overland flow (runoff that flows over the surface of the ground as a thin, even layer) or in minor swales or drainage ways.
- They prevent sediment from entering receiving waters.
- Silt fences are also used to catch windblown sand.
- Should not be used in streams.

Fig. 3.62: Silt fence
(Source: http://city.milwaukee.gov/CityLegacySite/SiltFence16800.htm)

e) Storm Drain Inlet Protection

- Storm drain inlet protection is a filtering measure placed around any inlet or drain to trap sediment.
- This mechanism prevents the sediment from entering inlet structures, thus, preventing the silting of inlets, storm drainage systems, or receiving channels.
- Inlet protection may be composed of gravel and stone with a wire mesh filter, block and gravel, filter fabric, or sod.

- It may be difficult to remove collected sediment.
- It is practical only for low sediment, low volume flows (disturbed areas less than one acre).

f) Sediment trap

- A sediment trap is formed by excavating a pond or by placing an earthen embankment across a low area or drainage swale. An outlet or spillway is constructed using larger stones or aggregate to slow the release of runoff.
- The trap retains the runoff long enough to allow most of the silt to settle out.
- Is inexpensive and simple to install, but suitable only for a limited area and is effective only if properly maintained.

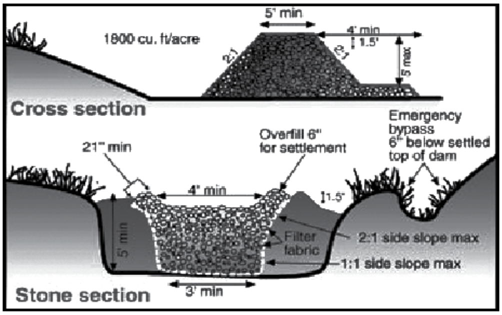


Fig. 3.63: Sediment trap
(Source: http://extension.missouri.edu/p/G1509)

Fig. 3.64: Outlet protection with rocks
(Source: http://livestockandland.org/Demonstration_Sites/pilot_site.html)

g) Outlet protection

- Outlet protection reduces the speed of concentrated storm water flows and therefore it reduces erosion or scouring at storm water outlets and paved channel sections.
- Also, it lowers the potential for downstream erosion.
- This type of protection can be achieved through a variety of techniques, including stone or riprap, concrete aprons, paved sections and settling basins installed below the storm drain outlet.
- But, may cause problems in removing sediment (without removing and replacing the outlet protection structure itself) and may require frequent maintenance for rock outlets with high velocity flows.

h) Check dams

- A check dam is a small, temporary or permanent dam constructed across a drainage ditch, swale, or channel to lower the speed of concentrated flows.
- Reduced runoff speed reduces erosion and gullying in the channel and allows sediments to settle out.
- Check dams should be used only in small open channels that will not be overtopped by flow once the dams are constructed.
- They are inexpensive and easy to install and may be used permanently if designed properly.
- It can be used where it is not possible to divert the flow or otherwise stabilize the channel.
- But it may kill grass linings in channels if the water level remains high after it rains or if there is significant sedimentation and reduce the hydraulic capacity of the channel.

Fig. 3.65: Surface roughened
(Source: http://www.nativerevegetation.org/learn/manual/ch_10_1.aspx)

i) Surface roughening

- Surface roughening is a temporary erosion control practice.
- The soil surface is roughened by the creation of horizontal grooves, depressions, or steps that run parallel to the contour of the land.

- Surface roughening reduces the speed of runoff, increases infiltration, and traps sediment and helps to establish vegetative cover by giving seed an opportunity to take hold and grow.
- It is of limited effectiveness in anything more than a gentle rain and is temporary as if roughening is washed away in a heavy storm, the surface will have to be re-roughened.
- **Important note:** Mitigation should be done according to real need of the specific site. Sometimes instead of reinforcement, simple remedial measure such as drainage would have helped. Also, sometimes pre-stressed anchors can be replaced by simple nailing or bolting. Therefore, measures need to be adopted according to site conditions as it will help economically and timely without hampering nature much.

3.5 Check for building failure

After taking all necessary steps for stability of slope, construction should be done according to Indian standard norms so that the building do not fail.

Also, proper measures need to be taken to protect building from falling debris or slope as mentioned above.

Some safe building practices to be followed are:

a) Maintain single, low-slope path down or across steep slopes;

b) Discourage as far as possible, play areas, caves and excavations on steep slope.

c) Design the house with split levels to minimise disturbance to the hill slope, thus controlling erosion and earth slip.

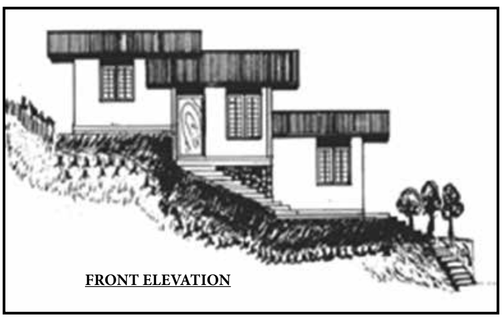


Fig. 3.66: Construction in split levels on slope
(Source: Asian disaster preparedness centre-engineering practices)

d) Retain natural vegetation to the maximum during site clearance.

e) Use flexible structures that incorporate properly designed brickwork, timber or steel frames, timber or panel cladding.

f) If any cutting is done before construction, make sure to keep it supported with engineered retaining wall or batter to the appropriate slope.

g) Filling material should be clean and well compacted. It should also be supported or battered to appropriate slope.

h) A structural ring beam around top of doors and windows and walls connected to columns should be provided to ensure structural integrity so that structure can act as one unit.

Fig. 3.67: Continuous ring beam over house
(Source: http://www.discoverycentres.org.uk/educationcentrepage.htm)

Fig. 3.68: Proper connection between roof and wall
(Source: https://www.disastersafety.org/high_winds/making-the-right-)connections/attachment/wall-to-roof-straps/)

i) All elements of the building should be properly tied together. Connections between posts, beams, columns, wall to wall framing should be ensured as it would not let the structure to break into separate elements.

Fig. 3.69: Reinforcement at corners of walls
(Source: http://blogs.gazette.com/sidestreets/2013/05/03/flashflood-sandbagging-off-to-poor-start)

Fig. 3.70: Sandbags put around house
(Source: www.ratecore.com)

j) Triangular gable end walls must be structurally supported.

k) Reinforcement provided need to be kept safe from corrosion through proper concrete cover.

l) The mud or adobe walls, brick piers, corners and perimeters of opening must be reinforced.

m) Proper engineered block walls should be constructed to save the house from debris flow.

n) Put sandbags or timber deflectors to direct debris away from house.

o) Use removable window and door protections like plywood, steel shutters for debris flow.

p) The house shall be built parallel to the contour lines and not perpendicular to it.

q) Concrete grade to be used in the construction which should be according to site conditions.

Table 3.1: Minimum cement grade to be used (according to environmental conditions)

S.No.	Environment	Exposure conditions	Minimum grade of concrete	
			Plain Concrete	Reinforced Concrete
1.	Mild	• Concrete surfaces protected against weather or aggressive conditions except those situated in coastal areas.	-	M 20
2.	Moderate	• Concrete surfaces sheltered from severe rain or freezing while wet. • Concrete exposed to condensation and rain. • Concrete continuously under water. • Concrete in contact or buried under non-aggressive soils/ ground water. • Concrete surfaces sheltered from saturated salt air in coastal areas.	M 15	M 25

3.	Severe	• Concrete surfaces exposed to severe rain, alternate wetting and drying or occasional freezing while wet or severe condensation. • Concrete completely immersed in sea water. • Concrete exposed to coastal environment.	M 20	M 30
4.	Very severe	• Concrete surfaces exposed to sea water spray corrosive fumes or severe freezing conditions while wet. • Concrete in contact with or buried under aggressive sub-soil/ground water.	M 20	M 35
5.	Extreme	• Surface of members in tidal zone. • Members in direct contact with liquid/soil aggressive chemicals.	M 25	M 40

- Portland pozzolana cement may be used to control and reduce the activities of the sulphates present in underground water or soil.
- Special cements like high alumina cement, super sulphated cement, that are sulphate resistant, may be used.

r) Proper loads and forces like earthquake forces and shrinkage, creep and temperature effects upon buildings should be calculated as per IS 875.

s) Structures should be built safe against sliding and overturning, possible through engineering practices.

For buildings to stand safe, most important is its foundation as if foundation fails, building will fail.

3.5.1 Design of Foundation

3.5.1.1 Some important consideration for construction of foundations

- Foundation if possible should be built on rock especially, when during excavation, cavities have been found.
- If, raft foundation is constructed, it should not overhang at any corner.

Fig. 3.71: Crack in house due to tree roots
(Source: http://www.guntherhomeinspections.com/ft_foundation_trees.htm)

- If foundation on rock is not feasible, excavate the soil and backfill it with concrete of required strength. Foundation should never be built on top soil.
- If rock for foundation is fissured, then required rock stabilising measures should be taken. Like grouting, anchoring etc.
- No trees that grow to a large size shall be planted within 8 m of foundations of buildings.
- Trees planted in hard compacted soils generally grow near the surface of the soil and pose less threat of harm to your property.

a. New constructions may interfere with drainage regime of the ground and affect the stability of existing structure so adequate precautions should be taken to protect these.

- On the uphill side of a building on a sloping site, land drainage requires special consideration for diverting the natural flow of water away from the foundations.
- If excavation involves cutting through existing land drains, consideration should be given for diverting them into the ground-drainage system.
- Chemical analysis of samples of ground water and soil should be done to assess the necessity of special provisions and use of concrete as per the environment conditions.

- Use rows of piers or strip footing oriented up and down slope.
- Design the footing for lateral creep pressures.
- Properly backfill the footing excavations, to exclude ingress of surface water.
- House built in a swampy, waterlogged area is unsafe as foundations remain permanently in wet soil that can slip, when impacted by any external hazard.
- Leakage from water mains and underground sewers may result in large volume changes. Therefore, proper drainage control needs to be done.
- Ground improvement as per soil stabilisation techniques needs to be followed.

3.5.1.2 Depth of Foundation

1. Clay soils, like black cotton soils, are seasonally affected by shrinkage and cracking in dry and hot weather, and by swelling in the following wet weather to a certain depth. Thereupon, these should be properly stabilised before construction or depth of foundation should be below this level.
2. In fine sands and silts, depth should be below the expected frost zone.
3. The maximum depth of scour by rainfall or root holes by burrowing animals should be considered and the foundation should be located sufficiently below this depth.
4. All foundations shall extend to a depth of at least 50 cm below natural ground level.

3.5.1.3 Type of Foundation Preferred in Hilly Regions

a) Shallow foundations

If the bearing capacity of soil is good at a shallow depth or rock is found below the ground surface, shallow foundation is preferable.

i) Raft foundation

Raft foundation is a thick concrete slab reinforced with steel and covers the entire contact area of the structure like a thick floor. Sometimes area covered by raft may be greater than the contact area, depending on the bearing capacity of the soil underneath. The reinforcing bars runs normal to each other in both top and bottom layers of steel reinforcement.

ii) Strip foundation:

Strip foundation consists of a continuous strip, usually of concrete, formed centrally under load bearing walls. This continuous strip serves as a level base for the wall to be built on it of width, necessary to spread the load on the foundation to an area of subsoil capable of supporting the load without undue compaction.

Fig. 3.72: Raft foundation
(Source:http://www.geodomisi.gr/Geodomisi_Ltd_Albums_1/album/slides/RAFT-FOUNDATION-PERDICOVOUNI_DSC00032.html)

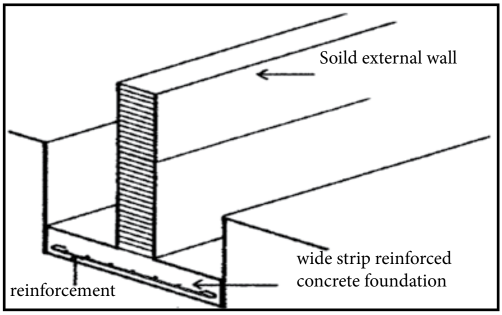


Fig. 3.73: Strip foundation
(Source: http://civilconstructiontips.blogspot.in/2011/06/wide-strip-foundation.html)

b) Deep foundations

If the soil just below the ground surface is not strong enough, but a strong stratum exists at a greater depth then deep foundation is preferred.

i) Pile foundation

A pile is a long, slender column made of steel, concrete, wood or in combination of two materials, positioned vertically in the ground or at an angle (battered) transferring the load to more stable strata, usually rocks. They do not cause massive land form alterations or long-term surface disturbance.

It is driven in the soil or can be installed at the site by drilling hole and then filling it with concrete.

They are best suited for highly compressible and weak under ground surface and reduce differential settlement possible due to irregular load distribution.

ii) Drilled pier

A drilled pier is a large diameter concrete cylinder built in the ground by drilling large hole and putting concrete in it. It differs from pile in size, generally larger than 0.6m diameter.

In hilly areas, pile foundations or drilled pier is preferred and also sometimes used in combination with raft foundation.

It can be constructed in- situ i.e., at site by drilling hole and pouring concrete or can be precast i.e., constructed off site and installed at site when required.

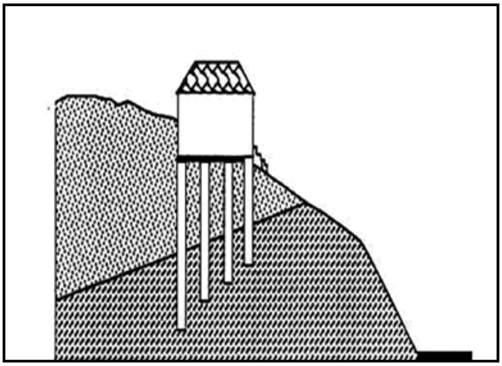


Fig. 3.74: Pile foundation

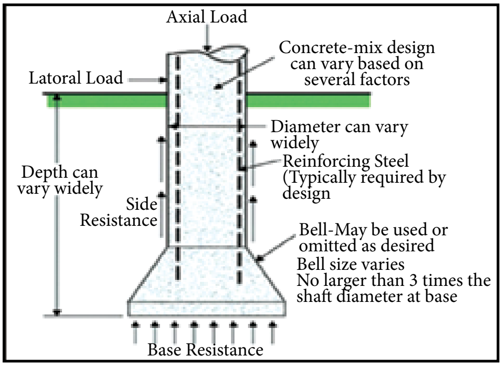


Fig. 3.75: Drilled pier
(Source: http://www.nationaldriller.com/articles/86777-drilled-shaft-construction-part-1?v=preview)

4. CONTEMPORARY BUILDING MATERIALS USED IN HILLY AREAS AND REQUIRED CHANGES

4.1 Alternate building materials suitable over traditional materials

New/improved building materials shall be used instead of traditional materials as mentioned below due to their better properties and effectiveness, compared to traditional materials.

Table 4.1: Traditional vis a vis alternate building materials

Traditional materials	Alternate building materials
Walling materials – Earth, soil, wood, timber, bamboo, bamboo mat, corrugated galvanized iron sheets, stone bricks, concrete, asbestos cement sheets, lime, cement, ekra, slates	Hollow concrete blocks, precast stone blocks, concrete blocks, and stabilised soil blocks can be used.
Roofing material – wood, timber, bamboo, bamboo mat, corrugated galvanised iron sheets, reinforced cement concrete, concrete, thatch, asbestos cement sheets, slates, country tiles, lime, cement, plastic sheets Flooring- earth, soil, wood, timber, stone, bricks, concrete, slates, lime, cement	Precast reinforced concrete L panel, partially precast reinforced concrete planks, joists, precast reinforced concrete channel units, fire retardant thatch, aluminum fiber reinforced plastic roofing sheets should be used

4.2 Important points for construction

Table 4.2: Construction consideration for different types of houses

Type of houses	Considerations for construction:
Earthen houses- Made up of clayey earth in mud lump form or rammed in rectangular shaped blocks.	• Fibrous materials like straw, hay, human or animals hair shall be mixed in natural soil • Minimum 300-350 mm thickness shall be adopted for low rise houses. • Wood elements or splitted bamboo should be inserted between courses particularly at corners and T- junctions of wall. • Floor shall be of wooden joists and planks. • Joists shall rest on wall plates • Composite wall construction of burnt bricks on outside face and non-burnt on inner side built in mud mortar, bonded together by header bricks shall take place.

Burnt Brick Houses – Burnt bricks made up of Clay, hand or machine moulded.	• Room width shall not be more than 3 to 3.4 metres. • Room length shall not be more than four to eight meters. • English bond shall be used for construction of one brick thick wall. • Mud mortar for single storeyed and cement or lime mortar shall be used for double storeyed load bearing walls. • Foundations shall be stepped over rammed earth and brick bats. Under or over burnt bricks shall be avoided. • Wooden ring beams on top of walls shall be provided to receive hipped roof.
Stone masonry houses – Made up of natural stones in masonry work.	• Mortar shall be cement or lime. • Wall thickness shall vary from 400 to 750 mm depending upon loading and mortar used. • Single storey laterite stone wall shall be 250 to 300 mm thick with hipped roof. • Single storey stone house with reinforced concrete slab roof and 2400 mm in height should be of typical design.
Wooden Houses – where main load bearing structure consists of wooden posts.	• It includes those in which one type is stud wall construction – wooden sill plates laid at plinth level and wooden posts, framed at short distance of 800 to 1200 mm Centre to Centre. It carries wooden plates at their top. Roof shall be pitched or hooped having wooden rafters and purlins. • Another type is nogged timber frame- consists of heavy corner columns, piers or posts, sills, intermediate verticals at 1000 mm centers. The wall plates, horizontal noggin members and diagonal braces on alternate panels shall be framed into each other. • Foundation of wooden houses should be random rubble masonry in mud mortar.
Concrete Frame and infill constructions	• The adobes, hollow concrete blocks, stone blocks, concrete blocks or stabilised soil blocks should be used as non load bearing, non structural infill. • Foundation should be strong and leveled with moisture barrier. • Reinforced cement concrete columns in each corner, implanted in foundation at least 750 mm deep. • Reinforced concrete ring beams shall be provided at top, bottom and middle of the wall.

5 THINGS TO DO BEFORE LANDSLIDES

- Avoid landslide hazard by following proper land-use procedures-Avoid building near steep slopes, close to mountain edges, near drainage ways or along natural erosion valleys.
- Learn whether debris flow have ever occurred in your area by contacting local officials. Slopes prone to debris flows are likely to experience the same in the future.
- Get a ground assessment of your property time to time from experts.
- Take appropriate preventive measures for your home or business, such as flexible pipe fittings, as it can resist breakage.
- Adopt retrofitting techniques as required.
- Keep note of landslide warning signs.
- To begin preparing, you should build an emergency kit like food supply, important documents and few medicines and make a family communication plan required after disaster.
- Prepare at least two evacuation routes in case one of them gets blocked by debris and practice them.

5.1 Landslide Warning Signs

- There is no particular warning for landslide occurrence, but keeping in check few landslide warnings, disaster can be averted.

Fig. 5.1: Cracking or slumping of embankment slopes
(Source: http://peer.berkeley.edu/publications/nisqually/geotech/earthstructures/)

Fig. 5.2: Cracking or falling of material from excavated slopes
(Source: http://wncsos.blogspot.in/2011_07_01_archive.html)

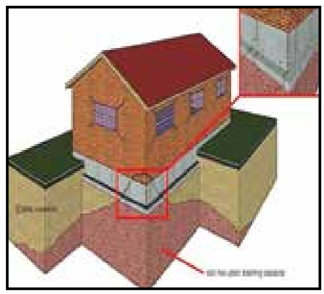


Fig. 5.3: Cracks occurring in cement
(Source: www.nachi.org)

- Cracking or falling of material from excavated slopes.
- Cracking or slumping of embankment.
- Soil moving away from foundation.
- Cracking of walls, retaining structures, concrete floors or foundations, indicates the unstable ground.
- Sticking doors and windows, and visible open spaces, indicates jamb and frames out of line because of moving ground.
- Water breaks through the ground surface from new locations.
- Rapid increase or decrease (though rainfall is falling) in water levels of natural stream.

Fig. 5.4: Tilting of walls
(Source: www.quora.com)

Fig. 5.5: Fractured water pipes
(Source: http://simscience.org/cracks/advanced/cracks1.html)

Fig. 5.6: Sunken and cracked road surface
(Source: https://lh6.ggpht.com/)

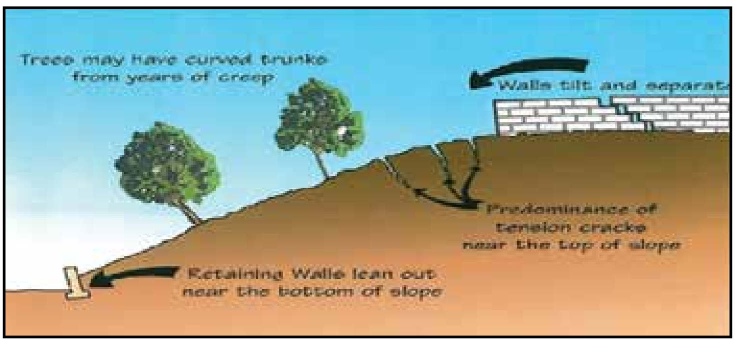


Fig 5.7: Warning signs
(Source: http://gabion1.com/retaining_wall_site_profile.htm)

- A faint rumbling sound that increases in volume can be heard when a landslide nears.

- Tilting of walls, telephone poles, power lines, trees, or fences indicates an impending landslide.
- Broken/fractured water pipes and underground facilities.
- Sunken or cracked road surfaces or unusual bulging of ground surface.
- Unusual sounds, such as trees cracking or boulders knocking together, might indicate moving debris.
- Rapid water or muddy flow, where it has not been observed before.
- Irregular or suddenly stopped stream flow.
- Electrical wires attached to the polls in the ground near the edge of the hill will become very tight as the polls move with the ground.
- If scars develop as a result of earth movement or water runoff, immediate remedial action is needed as the condition will worsen.

5.2 Maintenance of Buildings

- Seal all tension cracks in building on time.
- Get the drains cleaned up timely to ensure no clogging of water.
- Ensure all the safety measures before monsoons for your house and vicinity.
- Protect your property by planting on slopes and building engineered retaining walls.

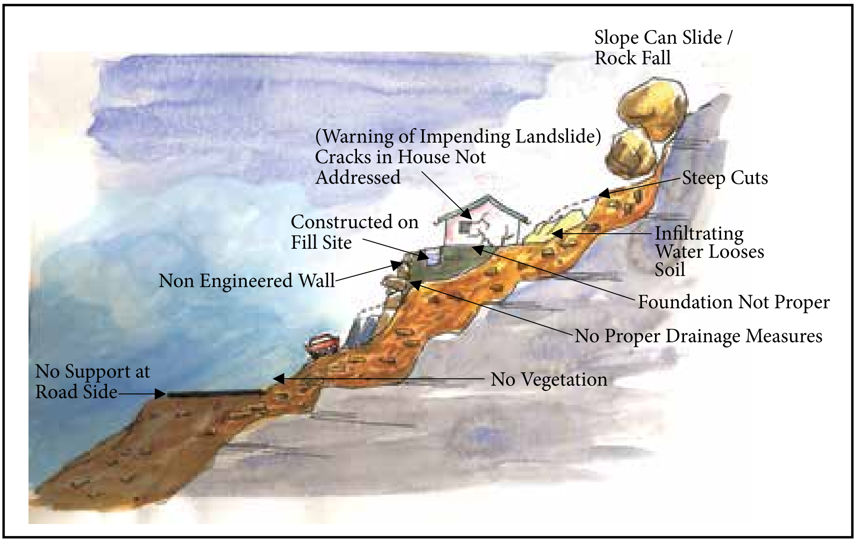


Fig. 5.8: Poor hillside construction practice
(modified after Australian Geomechanics Society, 2007)

Roadways and parking areas: Un-surfaced roadways and improper gutters cause surface water to pond and soak into the ground creating water pressure in soil.

Cut and fill: Unstable cut faces and large surface loads to the ground cause instability. Failure to compact the fill properly leads to settlement. The house built on fill usually settles with it and cracks. Leakage from the cracked pool and the applied surface loads from the fill, combines to cause landslides.

No retaining walls: Ignoring the importance of retaining wall to minimise cost, and using hand placed rock instead, fails to provide the required support to the ground.

A heavy, rigid, house: House built on shallow, conventional, footings is at high risk. The brickwork cracks because of the resulting ground movements and become involved in a man-made landslide.

No proper drainage: No proper drainage for sewage and surface water run-off from roofs and pavements make water soak into the ground, raising the ground water table leading to pressure on soil sediments.

Vegetation: Completely cleared vegetation causes possible rise in the water table and increases the landslide risk.

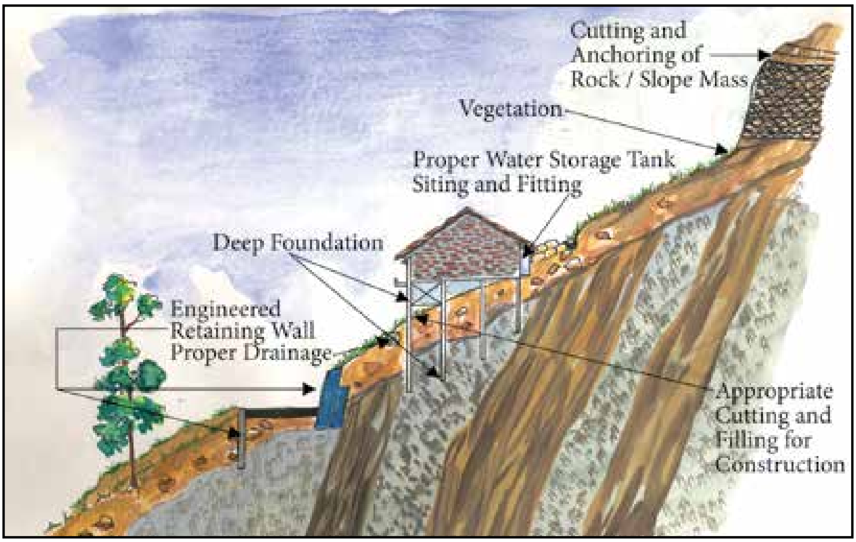


Fig. 5.9: Good hillside construction practice
(modified after Australian Geomechanics Society, 2007)

Proper roadways and parking areas: Roadways shall be paved and kerbs shall be incorporated to prevent water discharge straight into the hillside.

Cuttings: They must be supported by engineered retaining walls.

Retaining walls: They should be engineered, designed to withstand the lateral earth pressures and surcharges expected, and drains should be included to prevent water pressures developing in the backfill.

Sewage: Whether treated or not, sewage must be taken away in pipes or contained in properly founded tanks so it doesn't soak into the ground.

Surface water: Properly drained from roofs and other hard surfaces shall be piped away to a suitable discharge point rather than being allowed to infiltrate into the ground.

Surface loads: They must be minimised. Fill embankments should not be built. Foundation loads should be taken down below the level at that a landslide is likely to occur and, preferably, to rock.

Vegetation clearance: On soil slopes, it shall be kept to a reasonable minimum. Trees and smaller vegetation, take large quantities of water out of the ground every day lowering the ground water table, eventually maintaining the stability of the slope.

Drainage: Flexible drainage pipes are must to ensure the removal of excess water from soil, whether its storm water or irrigated water.

6 THINGS TO DO DURING LANDSLIDES

- During a severe storm, stay alert and awake. Many deaths from landslides occur while people are sleeping.
- Listen to local news stations on a battery-powered radio for warnings of heavy rainfall.
- Listen for unusual sounds that might indicate moving debris, such as trees cracking or boulders knocking together.
- Move away from the path of a landslide or debris flow as quickly as possible. The danger from a mudflow increases near stream channels and with prolonged heavy rains. Mudflows can move faster than you can walk or run. Look upstream before crossing a bridge and do not cross the bridge if a mudflow is approaching.
- Avoid going near river valleys and low-lying areas during heavy rainfall and during high flow of water.
- If you are near a stream or channel, be alert for any sudden increase or decrease in water flow and notice whether the water changes from clear to muddy. Such changes may mean that there is debris flow activity upstream, so be prepared to move quickly.

- If you are inside a building during a landslide, hide under a piece of sturdy furniture.
- Curl into a tight ball and protect your head if escape is not possible.

7 THINGS TO DO AFTER LANDSLIDES

- Stay away from the slide area. There may be danger of recurrences.
- Listen to local radio or television stations for the latest emergency information.
- Watch for flooding, that may occur after a landslide or debris flow. Floods sometimes follow landslides.
- Check for injured and trapped persons near the slide, without entering the direct slide area.
- Give first aid facility if trained or call rescuers for help.
- Look for and report broken utility lines and damaged roadways and railways to appropriate authorities. Reporting potential hazards will get the utilities turned off as quickly as possible, preventing further hazard and injury.
- Check the building foundation, chimney, and surrounding land for damage. Damage to foundations, chimneys, or surrounding land may help you assess the safety of the area.
- Replant damaged ground as soon as possible since erosion caused by loss of ground cover can lead to flash flooding and additional landslides in the near future.
- Seek advice from a geotechnical expert for evaluating landslide hazards or designing corrective techniques to reduce landslide risk.
- Check for damaged utility lines. Report any damage to the utility company.

8 SOME IMPORTANT POINTS

- Before taking up any construction, adopt planned outlay involving geologists, engineers and planners for allocation and zoning of land for specific uses, regulation of the intensity of use, and formulation of legal and administrative instruments that support the plan.
- Construct engineered buildings and keep yourself updated with near land deformations.
- Mostly landslides occur at same place again and again, so be informed.
- Adopt construction practices that adhere to Indian Standards as mentioned in references.

References

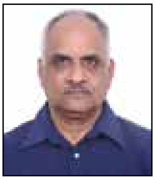
- Asian Disaster Preparedness Centre - Demonstration Housing Construction for Landslide and Flood Prone Areas
- Asian Urban Disaster Mitigation Programme – Demonstration Housing Construction for Landslide and Flood Prone Areas.
- Australian Geoguide prepared by Australian Geomechanics Society
- Comprehensive Landslides Risk Management: Training Module – Dr. Surya Parkash
- Field Guide by Gordon Keller & James Sherar, USDA Forest Service/USAID
- International Centre for Geohazards- Engineering measures for slope stabilization guide.
- IS 1904-1986: Code of Practice for Design and Construction of Foundations in Soils: General Requirements.
- IS code 14558:1998 (Part- 1): Retaining wall for Hill area- Guidelines.
- IS code 14680:1999: Landslide control-Guidelines.
- IS code 14804:2000 : Siting, Design and Selection of Materials for Residential Buildings In Hilly Areas -Guidelines
- IS-456:2000: Indian standard- Plain and Reinforced Concrete- Code of practice
- Low volume roads: BMPs- Best Management Practices.
- Reading material on comprehensive landslides risk management by NIDM
- Soil mechanics and Foundation Engineering book by Dr. K.R. Arora.
- The Landslide Handbook—A Guide to Understanding Landslides, By Lynn M. Highland, United States Geological Survey, and Peter Bobrowsky, Geological Survey of Canada.
- Unites States Geological Survey - USGS landslide mitigation guide.

Some Source links:

- http://saarc-sdmc.nic.in/pdf/landslide.pdf
- http://landslides.usgs.gov/learn/prepare.php
- http://darjeeling.gov.in/geography.html

- http://www.ce.washington.edu/~liquefaction/html/how/resistantstructures.html - Excerpts for liquefaction
- http://web01.redland.qld.gov.au/robo/rps/rps-v5-1/Part_11_-_Planning_Scheme_Policies/11.15_-_Landslide_Hazard.htm
- http://www.fao.org/docrep/v4360e/V4360E08.htm

Review



Normally, the hills are serene, beautiful, soothing, less polluted, and hence healthy and enjoyable places to stay. But most of these, especially the slope areas, suffer from one of the most dangerous hazard, the landslides. Driven by spiralling costs and insatiable demand for land here, as in many other places in cities and towns, there is spurt of construction activities in all three dimensions. Many a times a civil structure is developed without undertaking proper studies, and in cases if these have been done, not fully complying with their recommendations. The situation is alarming, rather it is continuously being made grave by unscientific human indulgence. The prime question is how much a land can bear in landslide prone areas? Yet..!

The present write-up, discussed with the help of true examples and supporting diagrams and illustrations, will surely help in identifying vulnerable areas and in capacity building of urban planners, developers, builders, architects and all other stakeholders, thereby safeguarding the civil structures and more importantly precious human lives. The work also discuses building codes on development and civil/engineering structures and dire need for strict adherence/enforcement of rules and regulations. Thus the life becomes more safe, meaningful and truly enjoyable.

I compliment Dr. Surya Prakash and NIDM for preparing the present write-up and am happy to have interacted with the author in that.

28 September 2019

(Sanjiv Sharma),
Dy. Director General (Retd.),
Geological Survey of India,
Ministry of Mines
New Delhi

bmtpc

डा० शैलेश कु० अग्रवाल, एम०ई०,पी०एच०डी०
कार्यकारी निदेशक

Dr. Shailesh Kr. Agrawal, M.E., Ph.D.
Executive Director

निर्माण सामग्री एवं प्रौद्योगिकी संवर्द्धन परिषद्
आवासन और शहरी कार्य मंत्रालय, भारत सरकार
Building Materials & Technology Promotion Council
Ministry of Housing & Urban Affairs, Government of India

Review

I am pleased to review the entitled "Landslide Preparedness Guidelines for Safety of Building on Slopes". The author has made a commendable effort to provide a basic idea of landslides, its causes/triggering factors as well as mitigation measures for construction and management of buildings. Landslides as secondary hazard as a result of earthquake and precipitation have also been covered in the guidelines. Precaution is always better than cure. The suggested approach for integration of landslide mitigation measures and building laws/codes will be effective in ensuring safer sustainable development in landslide risk zones. Incorporating the provided mitigation measures in every stage of any structure / building will be more economical than retrofitting any existing structure or building. Potentially the document will guide the land use planners, policy makers, home-owners and personnel from construction industry to reduce the landslide risks and become resilient against the adverse impact of landslides disasters.

The present document is the need of the hour as the consequences of landslide disasters have been rising many fold with accelerated pace of development and new infrastructure. Negligence of landslide mitigation measures before and during the construction activities on landslide susceptible slopes have also increased the toll of losses. The document gives an insight into the understanding of landslides, its impacts as well as mitigation measures to abate landslide risks if the construction is unavoidable on slopes that are prone to such hazards.

10 October 2019

(Dr.Shailesh Kr.Agrawal)
Executive Director

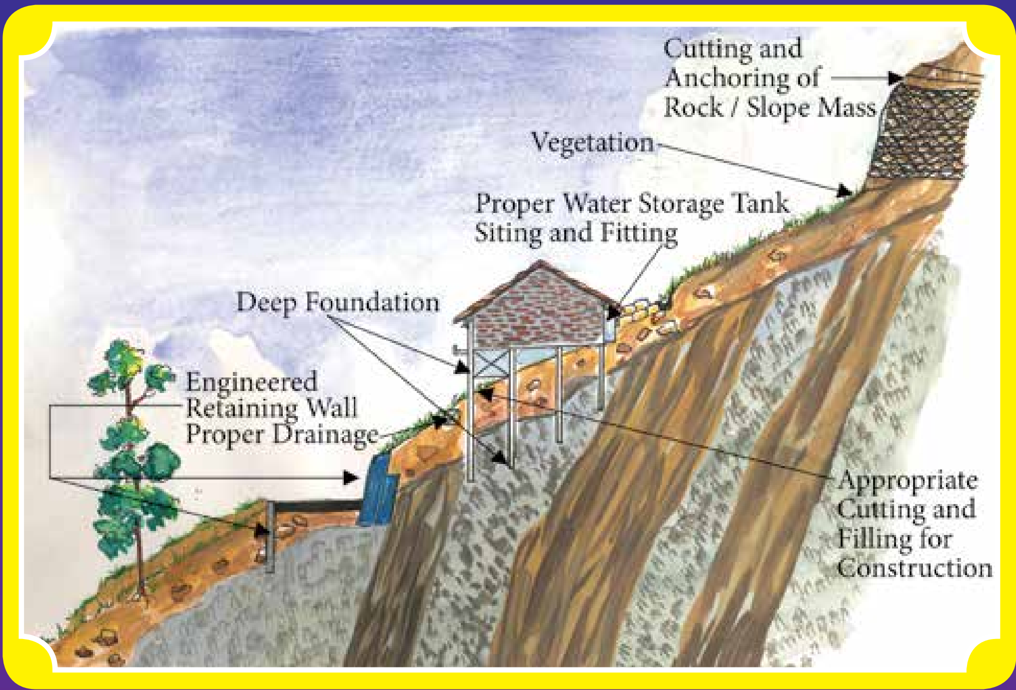
हम हिन्दी में किये गये पत्राचार का स्वागत करते हैं।
कोर 5ए, प्रथम तल, भारत पर्यावास केन्द्र, लोदी रोड़, नई दिल्ली – 110003; दूरभाषः 91–11–24636705; फैक्सः 91–11–24642849
Core 5A, 1st Floor, India Habitat Centre, Lodi Road, New Delhi - 110 003; Tel: 91-11-24636705; Fax: 91-11-2464 2849
E-mail: info@bmtpc.org; bmtpc.ihc@gmail.com Website: www.bmtpc.org

About the Author

Dr. Surya Parkash, Ph.D. (IITR), PGT (Geneva), PGT (Skopje), SDT (Ankara)
Head, Geo-Meteorological Risks Management Division,
National Institute of Disaster Management,
Ministry of Home Affairs, Government of India
Email: surya.nidm@nic.in

Surya Parkash is doctorate in earth sciences with specialisation in Geohazards Risk Management from Indian Institute of Technology, Roorkee. He did graduation and post graduation with Honours from a Centre of Advanced Study in Geology at Chandigarh. He qualified GATE, NET, TOEFL and GRE tests for pursuing research and teaching. He received University Scholarship, UGC's National Merit Scholarship, CSIR fellowship in his careers at UG, PG and PhD levels. He obtained specialised training on Disaster Risk Management from University of Geneva, Switzerland; IIZIS- Skopje, Macedonia and Middle East Technical University, Ankara, Turkey.

Professionally, he worked with prestigious institutes/universities like Central Building Research Institute, Roorkee; IIT Roorkee; JNU, New Delhi; Wadia Institute of Himalayan Geology, Dehradun; Forest Research Institute University, Dehradun; Vellore Institute of Technology University, Vellore and Recognised Qualified Professional Geologist by the Indian Bureau of Mines, Government of India. He was coordinator of the Indo-Japanese Cooperation on landslides under Security Declaration signed by Prime Ministers of India and Japan. He has been Team Leader for World Centre of Excellence on Landslide Disaster Reduction (2011-2014) conferred by International Consortium on Landslides (ICL) to NIDM and also the Project Leader for IPL-172 under International Programme on Landslides, jointly approved by UNESCO and ICL. He is currently Head of the Geo-meteorological Risks Management Division, Faculty Incharge of 3 specialized centres - Centre for Hill Area Development, Centre for Early Warning and Communication and Centre for Coastal Disaster Risk Reduction and Resilience as well as coordinating faculty for 8 Central Ministries, *i.e.*, Mines, Communication, Northeastern States, Petroleum & Natural Gas, Shipping, Labour & Employment (DGMS), New & Renewable Energy and Parliamentary Affairs.



Resilient India - Disaster Free India

A-Wing, 4th Floor, NDCC-II Building, Jai Singh Road,
New Delhi - 110 001 (India)
Website: www.nidm.gov.in