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Landslide Risk Assessment and Mitigation: State of Art

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Abstract

Landslides are defined as down slope movement of debris rock, and earth under the influence of gravity. Slide is one of the most common types of hazard on slopes, which might lead to considerable casualties and economic loss. The study and analysis of slope is essential in understanding their performance and in particular, their reliability, deformations and stability. The aim of the study is to analyze the typical slope by varying different soil parameters like angle of internal friction, cohesion, water table and slope geometry such as slope height and slope angle. The study further is directed towards the assessment of stability of landslides that have taken place in Pune. Also various measures to mitigate risk have been studied in detail.

Keywords: Landslide, Stability, Cohesion, Slopes, Mitigate

Introduction

A landslide, also known as a landslip or mudslide, is a form of mass wasting that includes a wide range of ground movements, such as rock falls, deep failure of slopes, and shallow debris flows. Landslides can occur below water, called a submarine landslide, coastal and onshore environments. The term landslide denotes “the movement of a mass of rocks, earth or debris down a slope” [1]. As human activity increases average global temperature, changing climate conclusively impacts slope stability and typical patterns of landslide occurrence [2]. The action of gravity is the primary driving force for a landslide to occur, other factors affecting the original slope stability. The materials may move by falling, toppling, sliding, spreading or flowing [3]. In general, changing precipitation patterns increase subsurface saturation and pore pressure; as average temperatures rise, total precipitation is also likely to increase, as well as the frequency of high-intensity rainfall events at northern high latitudes [4, 5]. Landslides should not be confused with mudflows, a form of mass wasting involving very to very rapid flow of debris that has become partially or fully liquefied by the addition of consequence amounts of water to the source material. To this aim, a scientifically advanced approach to landslide risk management is required, in order to improve the quality of life and reduce the risk trade-off among different decisional strategies [6, 7, 8]. The factors affecting landslides can be human-made or geophysical, they can occur in developed areas, undeveloped areas, or any area where the terrain was altered for roads, houses, utilities or buildings [9, 10].

Materials and methods

The landslides represent a serious problem almost in all parts of the world, because they causes social losses and economic on private and public properties. Natural disasters have demonstrated the subversive power of sudden mass movements during a landslide, which continue to claim lives and cause substantial damage to property and infrastructure on an annual basis. Despite frequent occurrence of such natural hazards, considerable gaps remain in basic understanding and modeling of key triggering mechanisms and the spatial extension of scars and deposition zones. Landslide is either a natural process or it occurs as a result of human activities which disturb the stability of slope. These method different according to their size of the displaced mass, shape, moving mechanisms, velocity and other characteristics. They can occur on any terrain given the right conditions of moisture, soil, and the angle of slope. Part of the natural process of the earth's surface geology, landslide serves to redistribute soil and sediments in a process that can be in abrupt collapses or in slow gradual slides.

Movement of land during landslides:

Three important factors that control the type and rate of mass wasting that might occur at the Earth's surface:

i. Slope gradient: The steeper the slope of the land, the more likely that mass wasting will occur.
ii. Slope consolidation: fractured or poorly cemented rocks, Sediments and sediments are weak and more prone to mass wasting.
iii. Water: If slope materials are saturated with water, they flow easily and they may lose cohesion

There are four possible different stages of landslide activity:

i. Pre-failure stage- when the soil mass is continuous. This stage is mostly controlled by creep and progressive failure;
ii. Failure stage- the formation of a continuous shear surface through the entire soil or rock mass;
iii. Post-failure stage- it includes movement of the rock or soil mass involved in the landslide, from just after failure until it essentially stops;
iv. Reactivation stage- the soil or rock mass slides along one or several pre-existing shear surfaces.

Major landslides in India:

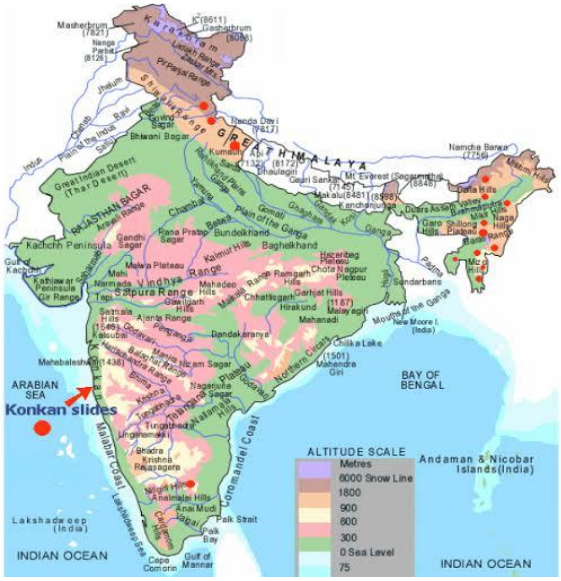

Figure 1 Major Landslides in India

Table 1 Recent Landslides

Date/Year	District/ State	Remarks
10 May 2005	Itanagar, Arunachal Pradesh	Nine people were killed and loss of property resulted.
June 2005	Nogli, HP	Severe damage was caused to 70 to 80 meters of the road due to heavy rain flash floods.
June 2005	Rampur, HP	The junction of the HPSEB Rest House road and NH-22 near the Chuhabagh area of Rampur town was Affected due to a landslide resulting from rainfall.
29-30 June 2005	Govindgaht, Chamoli, Uttarakhand	A cloudburst/landslide occurred in which huge quantities of debris and rock boulders were brought down along a seasonal Nala. 11 people were killed and property lost.
July 2005	Mumbai, Maharashtra	Caused death and loss of property in Mumbai. 4 dead on the Belapurkharghar road. 14 deaths at Nerul, and 100 deaths at sakinaka.
Aug 2005	Ratnagiri, Maharashtra	Places affected - Mandangad, Chiplun, andSangameshw artalukas. Destabilization of slopes affecting manmade features.
13 November 2006	The Nilgiris, Coimbatore, Karnataka	Between Burltar and Mettupalayam on NH-67, the road was washed off due to landslide.

Sep 2006	Doda, J&K	Between Ramsu and Batolte, there were many small slope failures and landslides due to heavy rains.
7 August 2006	Araku valley, Andhra Pradesh	Massive landslide occurred in Vishakhapattanam district A.P., at several places. 18 lives were lost and damage was caused to 10 to 15 dwelling units
7 August 2006	Dharla village, Himachal Pradesh	A landslide led to the burial of entire villages. Fourteen houses and one primary health center were buried under the debris/ 60 lives were lost.
6 September 2007	Village Baram/Sialdhar, Dharchula, Pithorgarh district, Uttarakhand	A landslide due to excessive rainfall resulted in 15 fatalities and loss of livestock
14 September 2014	Parampule dist., Arunachal Pradesh	17 people were killed in a series of landslides preceded by heavy rainfall.
30 July 2014	Malin village, Pune dist., Maharashtra	The landslide, which hit early in the morning while residents were asleep, was believed to have been caused by a burst of heavy rainfall, and killed at least 134 peoples. The landslide was first seen by a bus driver who drove by the area and saw that the village had been overrun with mud and earth. Also addition to those dead, more than 160 peoples, and possibly up to 200, were believed to have been buried 44 separate houses.

Figure 2 Rescue Team Working Hard To Remove The People Buried Under The Clay In Malin.

Concept of landslide

The type of movement of landslide is dependent on many factors including the type of material, slope gradient, and the hydrological conditions. There are six distinct types of landslide movement: fall, topple, slide, spread, flow, and complex.

1. Falls

Falls are precipitant movements of masses of geologic materials, such as boulders and rocks. A fall starts with the detachment of rock from a steep slope and no shear displacement take place. The material then descends mainly through the bouncing, or rolling. The material roll for considerable distances downslope forming talus slopes. Movement is rapid to high rapid with no prior indication. Except when the displaced mass has been undercut, falling will be preceded by small sliding or toppling movements that separate the displacing material from the undisturbed mass. They are very common, both in rock and debris, on steep slopes below bedrock scarps in upland areas. Falls occur in all types of rocks, especially along bedding planes, joints or local fault areas, or fault planes. There isn't reliable methods for calculating the stability of a slope with respect to falls. Soil falls may happen when an

effectively erodible material (clean sand or silt) underlies a more erosion-resistant material (over-consolidated clay). Falls are one of the main erosion mechanisms in heavily over-consolidated clays

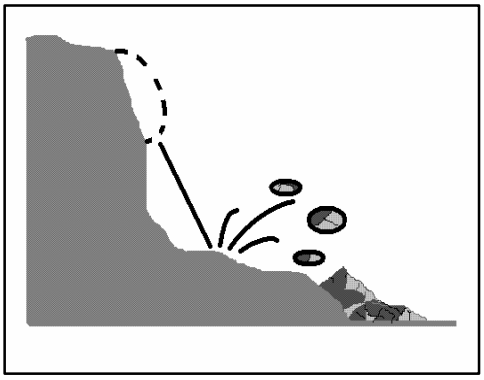

Figure 3 fall

2. Topples

A topple is the forward rotation out of the slope of a mass of soil or rock about axis below the center of gravity of the displaced mass. The rock mass may stay in place in this position for a long time or it may fall away down-slope due to further weakening or undercutting. This will depend on the rock type, the geometry of the rock mass, and the extent of the discontinuities. Topples range start extremely slow and end with extremely rapid, sometimes accelerating throughout the movement.

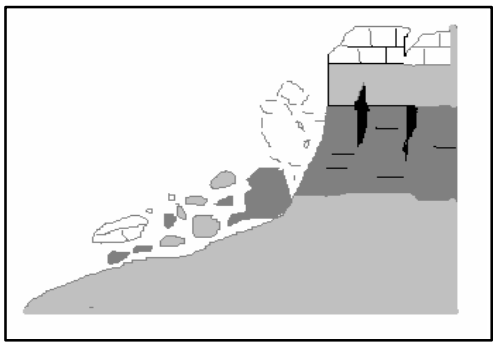

Figure 4 Topples

3. Slides

Slides implicate the displacement of masses of material along well-defined surfaces of rupture called slip or shear surfaces. The material moves in mass but is likely to break up with distance from the initial rupture point. A slide is a down-slope movement of a soil or rock mass that occurs on surface of rupture or on relatively small zones of intense shear strain. There are several types of slides, but one of the most common is a slump. A slump occurs when a part of hillside moves downslope under the influence of gravity. A slump has a characteristic shape, with a scarp at the top of the slump, and a bulge of material at the base of the slump. Slides are divided into rotational and translational slides. The movement occurs as a result of either sliding on discrete shear surfaces or ductile deformation within a shear zone.

a) Rotational slides

In this sliding on a shear surface which is concave upwards in the direction of movement where the displaced mass rotates about an axis which is parallel to the slope. The back of the slide is marked by a crack or scarp. Slope which is concentric in plan. The displaced mass may flow further down side of slope beyond the rupture surface to form a zone of accumulation at the toe of the total feature. Rotational slides can be one or more events.

b) Transitional slides

It is also called planar slides. The mass of material towards down side of slope on a largely planar surface. Translational slides can have very different impacts to rotational slides. Where the slope is sufficiently steep and the shearing resistance along the slip surface remains less, the movement can continue on for a large distance, being different to rotational slides. This slides in rock usually occur along discontinuities such as joints or bedding planes. Slopes where the discontinuities lie parallel to the ground surface would be more prone to translational sliding.

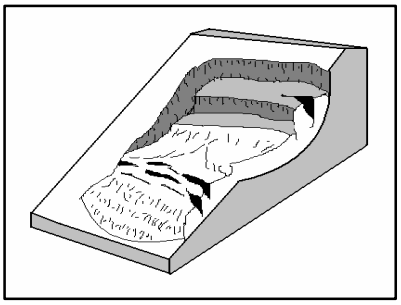

Figure 5 Rotational Slides

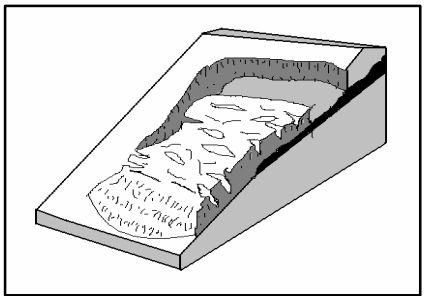

Figure 6 Transitional Slides

i.Spread

Spread is extension of a rock mass or cohesive soil combined with a general subsidence of the fractured mass of cohesive material into softer underlying material. Spread result from liquefaction or flow of the softer material. Spreads are distinctive because they usually occur on very dilute slopes or flat terrain. The dominant movement in spreads involves the lateral extension of the underlying weak material due to shearing or tensional fractures. It can be caused by liquefaction or plastic flow. Failure is usually triggered by rapid ground motion, as like that experienced during an earthquake, but can also be artificially induced.

ii.Flows

A flow is a continuous movement in which surfaces. The distribution of velocities in the displacing mass resembles that in a viscous liquid. The down side boundary of the displaced mass may be a surface along which appreciable differential movement has occurred or a thick zone of distributed shear. Gradation from slides to flows depends on mobility water content, and evolution of the movement. Characteristics as like scarps, toes, and seeps hint old landslide activity. Building on the toe of an archaic slide that reactivates can be devastating if buildings and roads are built on them. Once moving, many old landslides are very difficult to stop. Movement can occur after so many years of inactivity, so sites are never safe.

Causes of Landslide

1. Natural Causes:

Slope saturation by water is the primary cause of the landslide. Saturation can be happened because of intense rainfall, changes in ground-water levels and surface water level changes along coastlines, earth dams and in the banks of lakes, reservoirs, canals and rivers.

i.Rainfall

Rainfall causes landslide by loosening the soil compaction and also by increasing the weight of the soils of the hills.

ii.Earthquake

Earthquake may cause high intensity landslides as it reduces shear strength of soil particles. Earthquakes in steep landslide-prone zones hardly increase the likelihood that landslides will happen because of liquefaction of susceptible sediments or shaking caused dilation of soil materials, ground shaking alone. It allows rapid infiltration of water. Shear strength is controlled by a number of variables such as friction, which itself is proportional to the normal force, as well as many other variables such as the roughness, cohesion and dryness of the material.

iii.**Gravity**

The detachment of the mass of earth or rock from height down slope under the influence of gravity is referred to as mass movement. The same situation is observed in study area due to heavy cutting of sides for traffic movement. All the mass movements are primarily the result of gravity. Landslide is normally triggered due to shear failure of rock or soil forming the slope.

2. Human interventions

Expanding population in the landslide prone area due to migration are the primary means by which humans are contributing to the landslide disasters. The new settlement creates disturbance to the natural drainage system and destabilize the slopes. Unsustainable and unplanned use of land for industrial purpose and irrigation practice by the migrated people is also reducing stability of the soil for containing moisture and losing bondage of top soil. Landslide related human induced factors are given below:

i.Hill cutting

Currently hill cutting is one of the major causes of landslide. Hills are being cut for building construction; develop residential/housing area, clay and sand mining and developing road network. People build house on the top of the hills or foot of hills without following the existing rules and regulations. Greedy influential people and muscle-men invade the Government hills and build temporary houses on them to earn money by renting them to the poor people.

Poor people who live in those houses are highly risk to landslide. Because of hill cutting, the slopes become not stable. The hills are cut with slopes of 70-80 degrees. When it rains, water dissolves the minerals of the soil of the hills that loosen its compaction. Soils on hills also become heavy by absorbing rainwater. If rain intensity is too more, minerals of soil dissolve very quickly and the soil turns into mud form and becomes very heavy.

Figure 7 Hill cutting for brick field

Figure 8 Hill cutting for road expansion

ii.Deforestation

Vegetation constitutes a renewable resource, which contributes substantially to the economic development of all countries and plays a vital role in enhancing and preserving the quality of the environment. Man has exploited vegetation for his own purpose. Due to deforestation contribute direct expose of soil surface to wind and rainfall causes the landslide. Also the tree hold the slope materials together and enhance the resistance.

The occurrence of landslides includes a number of factors. The major studied factors responsible for causing landslides in study area

iii.Modern irrigation practice

Modern irrigation practice without considering the traditional knowledge loosens the bondage of soil particles. Rice terraces are disappearing frequently. People are more inclined to the crop production practice of flat plains. This concludes in the rapid disappearance of rice terraces, hills and forests.

iv.Inappropriate drainage system

Natural drainage lines on slopes are blocked to prevent soil disintegration and to expand percolation during dry season for cultivation, without sufficient arrangement for surface drainage of large amount of storm water during heavy rains increase the landslide risk.

Landslide warning signs

i. Soil moving away from foundations.
ii. Doors or windows stick or jam for the first time
iii. New cracks appear in plaster, tile, brick or foundations;
iv. Fences, retaining walls, utility poles or trees tilt or move;
v. Tilting or cracking of concrete floors and foundations.
vi. Broken water lines and other underground utilities.
vii. Leaning telephone poles, retaining walls or fences and trees.
viii. Sunken or down-dropped road beds.
ix. Sticking doors and windows, and visible open spaces indicating jambs and frames out of plumb.
x. Unusual sounds, such as trees cracking or boulders knocking together, might indicate moving debris.

Results and discussion

Mitigation of landslide

1. Stabilization

i. Grading unstable portion of the slope to lower gradient
ii. Construction of rock buttress
iii. Retaining wall and gabion wall
iv. Drainage improvements
v. Reinforcement of high tensile steel wire mesh (shotcrete) and secured with patterned ground anchors (soil nail)
vi. Bored piles
vii. Re-vegetation (hydro seeding and sodding)

2. Protection

- Protection measures for landslide primarily focus on containment and diversion of the moving debris. Measures include walls, berms, ditches and catchment basins which can be low to moderate in cost. However considering long term maintenance cost are often associated with this measures to clean out and dispose of accumulated debris.

i.Rock fall protection

- In many areas rock faces are 'stiched' with massive steel bolts to try to keep material from being lost to active weathering.
- Alternately surfaces can be covered with strong mesh and boulder catching nets can be used

ii.Mudflow barriers

- This kinds of barriers are designed to catch most sediment, but are not capable of stopping very large and very Fast moving debris

3. Maintaince and monitoring

Maintenance and monitoring measures include proactive clean out of available catchment area.

- Routine observation and assessment of slope condition, landslide warning (slide) monitoring slope.

- Equipment- inclinometer

- Frequency-1time/week & after heavy rain and earthquake

- Provide weather instrumentation to prevent closures

- This measures low cost & highly effective to reducing exposure to slide risk

4. Improving surface and subsurface drainage

Water is an important factor in landslides, improving surface and subsurface drainage at the site can expand the stability of landslide slope. Surface water should be moved away from the landslide-prone region by channeling water in a lined drainage ditch or sewer pipe to the base of the slope. The water should be moved in such a way as to avoid triggering a landslide adjacent to the site.

5. Excavating the head

Removing the rock and soil at the head of the landslide decreases the driving pressure and can slow landslide. Additional rock and soil above the landslide will need to be removed to prevent a new landslide from forming upslope. Flattening the slope angle at the top of the hill it can help stabilize landslide slopes.

6. Buttressing the toe

Toe of the landslide is at base of the slope, fill can be placed over the toe and along the base of the slope. The fill increases the resisting forces failure surface of toe area. However, if the toe is more on the slope, adding fill would overload the rock and soil below the toe, thus causing a landslide to form downslope of the fill.

7. Constructing piles and retaining walls

Piles are metal beams that are either placed in drill holes or driven into the soil. Proper placed piles extend into a competent rock layer below the landslide. Wooden beams and telephone poles are not recommended because they lack strength and can rot.

Retaining walls can be constructed by adding lagging (concrete, metal, wooden beams) horizontally between the piles. Such walls can be further strengthened by adding tiebacks and buttressing beams. Tiebacks are long rods that attach to the piles. Buttressing beams are placed at an angle downslope of the piles for prevent the piles from tilting or toppling. Retaining walls also are constructed of concrete, rock, cinder blocks, railroad ties, or logs, but these may not be strong enough to resist landslide movement.

8. Removal and replacement

Landslide prone soil and rock removed and replaced with stronger materials, such as sandy soils. Because weathering the removal and replacement method must include measures to prevent continued weathering of the remaining rock.

9. Preserving vegetation

Grasses, Trees, and vegetation can minimize the amount of water infiltrating into the soil, slow the erosion caused by surface-water flow, and remove water from the soil. Vegetation alone can't prevent or stop landslide, removal of vegetation from a landslide-prone slope may initiate a landslide.

Effects of Landslides

1. Decimation of infrastructure
2. Loss of life
3. Affects beauty of landscapes
4. Impacts river ecosystems
5. Destruction natural environment

Table 2 Landslides in Maharashtra

Date	Location	Problems
4/7/2019	Poladpur	Road (Transportation Problem)
8/7/2019	Khandala Khat(Pune-Mumbai)	Road (Transportation Problem)
10/7/2019	Jarakarwadi (Ambegavon)	Damages Agricultural
10/7/2019	Khed Ghat (Pune-Nashik highway)	Road (Transportation Problem)
11/7/2019	Aadoshi Tunnel (Lonavla)	Road (Transportation Problem)
13/7/2019	Bhuibada Ghat (Vaibhavwadi)	Road (Transportation Problem)
16/7/2019	Kolhapur	Road (Transportation Problem
16/7/2019	Parshuram Ghat (Mumbai-Goa)	Road (Transportation Problem
26/7/2019	Kumbhargani Ghat (Maldev)	Road (Transportation Problem
28/7/2019	Monkey Hill (Pune-Mumbai)	Landslide On Train tack
28/7/2019	Kushire Ghat (Ambegavon)	Road (Transportation Problem
28/7/2019	Monkey Hill-Thakurwadi (Lonavla)	Landslide On Train tack
30/7/2019	Palasdari-Jamrug (Pune-Mumbai)	Landslide On Train tack
31/7/2019	Khandala Ghat (Pune-Mumbai)	Road (Transportation Problem
4/8/2019	Tapola-Mahableshwar (Satara)	Road (Transportation Problem
5/8/2019	Khandala Ghat (Pune-Mumbai)	Landslide On Train tack
5/8/2019	Dive Ghat (Hadapsar)	Road (Transportation Problem
1/8/2019	Singhgaad Ghat (Pune)	Road (Transportation Problem
21/8/2019	Bhor-Varandha (Pune-Kokan)	Road (Transportation Problem

Conclusion

Landslides are a serious geologic hazard common to almost every State in the India. It is also very important to understand the science of landslides – their causes, movement characteristics, soil properties, and the geology associated with them, and where they are likely to occur and the suitable measures to be adopted to overcome it. The above details recommend that landslide in the area is because of the consolidated impact of the natural and anthropogenic activities. If without understanding the natural geological and geomorphologic and hydrological condition, anthropogenic activities, landslides could be more severe in the forthcoming days and hence proper measures is suggested. This would help us in planning protective measures and disaster management for the landslides for the safety and security of people. The study of different landslide movement are fall, topple, slide, spread, flow, and complex. The causes of landslides are like rainfall, earthquake, gravity, hill cutting, deforestation, modern irrigation practice, inappropriate drainage system. The mitigation measures of landslides are stabilization, Protection, excavating, removing the head, buttressing the toe, constructing piles and retaining walls, removal and replacement and preserving vegetation.

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