Landslides and Its Remedial Measures: An Overview

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Abstract— Landslides constitute one of the major natural disasters in the ecosystem. The fragile terrain often faces significant problems of geo-environmental imbalance due to landslides. The term' landslide' includes all varieties of mass movements of hill slopes and can be defined as the downward and outward movement of slope forming materials composed of rocks, soils, artificial fills or combination of all these materials along surfaces of separation by falling, sliding and flowing, either slowly or quickly from one place to another. Although the landslides are primarily associated with mountainous terrains, these can also occur in areas where an activity such as surface excavations for highways, buildings and open pit mines takes place.
Key words: highways, buildings, sliding, spreading

I. Introduction

Landslide is a general term for a wide variety of down slope movements of earth materials that result in the perceptible downward and outward movement of soil, rock, and vegetation under the influence of gravity. The materials may move by falling, toppling, sliding, spreading, or flowing. Some landslides are rapid, occurring in seconds,Whereas others may take hours, weeks, or even longer to develop.During and after landslides, material movement takes place as mudflow.Mudflows (or debris flows) are fluid mass of rock, earth, and other debris saturated with water. Mudflows are characteristics of steep, scanty vegetated slopes on which heavy rainfall initiates movement in a thick layer of weathered material. They develop when water rapidly accumulates in the ground, such as during heavy rainfall or rapid snowmelt, changing the earth into a flowing river of mud or slurry. Slurry can flow rapidly down slopes or through channels, and can strike with little or no warning at avalanche speeds. Slurry can travel several miles from its source, growing in size as it picks up trees, cars, and other materials along the way

Fig.1: Mudflow and Slurry Deposition

II. Types Of Landslides

The common types of landslides are described below. These definitions are based mainly on the work of Varnes (Varnes, D.J., 1978)

A. Falls

Abrupt movements of materials that become detached from steep slopes or cliffs, moving by free-fall, bouncing, and rolling.

B. Flows

General term including many types of mass movement, such as creep, debris flow, avalanche, lahar, and mudflow.

C. Creep

Slow, steady downslope movement of soil or rock, often indicated by curved tree trunks, bent fences or retaining walls, tilted poles or fences.

D. Debris flow

Rapid mass movement in which loose soils, rocks, and organic matter combine with entrained air and water to form slurry that then flows downslope, usually associated with steep gullies.

E. Debris avalanche

A variety of very rapid to extremely rapid debris flow.

F. Lahar

Mudflow or debris flow that originates on the slope of a volcano, usually triggered by heavy rainfall eroding volcanic deposits, sudden melting of snow and ice due to heat from volcanic vents, or the breakout of water from glaciers, crater lakes, or lakes dammed by volcanic eruptions.

G. Mudflow

Rapidly flowing mass of wet material that contains at least 50 percent sand-, silt-, and clay-sized particles.

H. Lateral spreads

Often occur on very gentle slopes and result in nearly horizontal movement of earth materials. Lateral spreads usually are caused by liquefaction, where saturated sediments (usually sands and silts) are transformed from a solid into a liquefied state, usually triggered by an earthquake.

I. Slides

Many types of mass movement are included in the general term "landslide." The two major types of landslides are rotational slides and translational landslides. which one described in the following paragraph.

1) Rotational landslide

The surface of rupture is curved concavely upward (spoon shaped), and the slide movement is more or less rotational. A slump is an example of a small rotational landslide.

2) Translational landslide

The mass of soil and rock moves out or down and outward with little rotational movement or backward tilting. Translational landslide material may range from loose, unconsolidated soils to extensive slabs of rock and may progress over great distances under certain conditions.

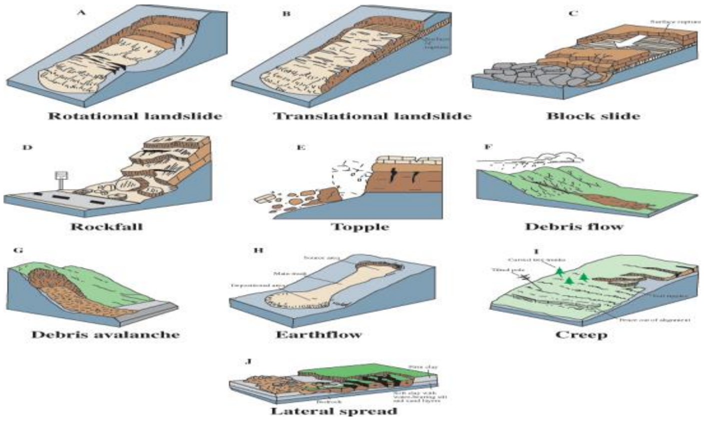

Fig. 2: Types of Landslides

III. REVIEW OF LITERATURE

Landslide is a major source of Disaster in areas with far-reaching and wide range effect to humans .It produces disturbance and impacts those are more severe than other forms natural disaster .The research work done by various authors in India and Abroad are given below:

A. R.K Panigrahi et al., (2009).

They studied about the landslide investigations and remediation techniques for National Highway pass through hilly areas (Terrains) of india and are important from the point of view of life line for inhabitants of those states.

B. S.P Satti et al., (2009).

They studied about the landslides in Uttarakhand at NH-58 and describes all the factors which involved to make landslides with the help of Remote sensing and geographical information system data available during that time and describes some control and mitigation process.

C. Anbalagan and Parida (2013).

Studied out the geoenviornmental problems due to Harmony landslides in Garhwal Himalya,Uttarakhand (India).This studied carried out some test related to soil strength like shear strength test by collecting soil from selected site and Factor of safety (F) was carried out using circular charts.The status of stability of the slide could be understood and accordingly suitable control measures for stablizing the hill slopes have been suggested.

IV. POINT OF OCCURANCE OF LANDSLIDES

A. Where they have occurred before

Large, deep-seated slides tend to be a reactivation of existing landslide complexes. Slope stability maps can provide an excellent indication of unstable areas. A competent geological analysis can usually provide an estimate of stability of problem areas on a site. It cannot reliably provide a probability of failure or an exact map of the area to be affected.

B. On steep slopes

Steep slopes are typically found along shorelines where centuries of wave or river currents have eroded the toe of the slope. Most steep slopes experience sliding.

C. On benches

Relatively level benches on an otherwise steep slope often indicate areas of past slope movement.

D. Where drainage is causing a problem

Landslides are often triggered by the failure of drainage systems. Large amounts of water flowing from driveways, roof areas, roads and other impermeable surfaces can cause slides.

Fig. 3: Kaliyasaur landslide (along NH-58) reactivated due to heavy rainfall in September 2010. It has become a major Bottleneck for vehicular traffic on the Rishikesh–Badrinath road.

V. AGENTS INFLUENCING THE OCCURRENCES OF LANDSLIDES

AGENT	EVENTS OR PROCESS THAT BRINGS THE AGENT INTO ACTION	MODE OF ACTION OF AGENT
1.Transporting agent	Construction operations or erosion	Increase of height or rise of the slope.

2.Tectonic stresses 3.Tectonics stresses or explosive 4.Weight of slope forming material 5. Water	Tectonic movements Earthquake or blasting Process that created the slope Rains or melting snow	Large-scale deformation of the earth crust. High frequency vibration Creep on slope Creep in weak stratum below foot of slope Displacement of air in voids. Displacement of air in open joints.

Source: (From Petak and Atkisson, 1982, Natural Hazards, Risk Assessment and Public Policy, Springer, New York.489 p.)

The different agents influencing the occurrences of landslide is given in table.1

VI. Causes Of Landslides

Many factors contribute to slides, including geology, gravity, weather, groundwater, wave action, and human actions. Although landslides usually occur on steep slopes, they also can occur in areas of low relief. Landslides can occur as ground failure of river bluffs, cut and-fill failures that may accompany highway and building excavations, collapse of mine-waste piles, and slope failures associated with quarries and open-pit mines. Underwater landslides usually involve areas of low relief and small slope gradients in lakes and reservoirs or in offshore marine settings. Typically, a landslide occurs when several of these factors converge.

A. Natural Factors

(1) Gravity: Gravity works more effectively on steeper slopes, but more gradual slopes may also be vulnerable.
(2) Geological factors: Many slides occur in a geologic setting that places permeable sands and gravels above impermeable layers of silt and clay, or bedrock. Water seeps downward through the upper materials and accumulates on the top of the underlying units, forming a zone of weakness.
(3) Heavy and prolonged rainfall: Water is commonly the primary factor triggering a landslide. Slides often occur following intense rainfall, when storm water runoff saturates soils on steep slopes or when infiltration causes a rapid rise in groundwater levels. Groundwater may rise as a result of heavy rains or a prolonged wet spell. As water tables rise, some slopes become unstable.
(4) Earthquakes: Seismic activities have always been a main cause of landslides throughout the world. Any time plate tectonics move the soil that covers moves with it. When earthquakes occur on areas with steep slopes, many times the soil slips causing landslides. Furthermore, ashen debris flows caused by earthquakes can also trigger mass movement of soil.
(5) Forest fire: fires cause soil erosion and induce floods and landslides due to the destruction of the natural vegetation. (eg. ridges of Manipur-Nagaland border).
(6) Volcanoes: Strato volcanoes are prone to sudden collapse, especially during wet conditions. (E.g. May 18, 1980, magma moved high into the cone of Mount St. Helens and shoved the volcano's north side outward by at least 150 m. Within minutes of a magnitude 5.1 earthquake at 8:32 a.m., a huge landslide completely removed the bulge, the summit, and inner core of Mount St. Helens, and triggered a series of massive explosions.) The conditions commonly prevail after volcanic eruptions that kill vegetation over extensive areas and spread loose volcanic rocks over the landscape. During subsequent rainy seasons, swollen rivers will erode the new deposits and sometimes generate lahars that are dangerous to people downstream. (E.g. lahars at Mount Pinatubo, Philippines in1990)
(7) Waves: Wave action can erode the beach or the toe of a bluff, cutting into the slope, and setting the stage for future slides.

B. Anthropogenic Factors

Human actions most notably those that affect drainage or groundwater, can trigger landslides e.g. are Inappropriate drainage system, change in slope/land use pattern, deforestation, agricultural practices on steep slopes, cutting & deep excavations on slopes for buildings, roads, canals & mining ,inappropriate disposal of debris after excavations are examples.

(1) Inappropriate drainage system:
Natural drainage lines on slopes are blocked by terracing/ contour bounding adopted to prevent soil erosion and to enhance percolation during dry season for cultivation, without adequate provision for surface drainage of excess storm water during high intensity rains increase the landslide vulnerability.
(2) (Cutting & deep excavations on slopes for buildings, roads, canals & mining: Developmental activities like construction of buildings, road cutting, embankments, cut and fill structures causes

modification of natural slopes, blocking of surface drainage, loading of critical slopes and withdrawal to toe support promoting vulnerability of critical slopes.

(3) Change in slope/land use pattern, deforestation, agricultural practices on steep slopes: Deforestation and cultivation of seasonal crops and increase in settlements. Improper land use practices such as heavy tilling, agricultural practices and settlement patterns have contributed to creep and withdrawal of toe support in many cases.

VII. DESTABLIZING FORCES AND MASS MOVEMENTS

A. Forces involved

1) Factors governing stability of slopes and causing mass movements are

(1) Slope angle and altitude
(2) Lithology
(3) Structures
(4) Hydrological conditions
(5) Seismicity in the areas

2) Forces operating on slopes are

(1) Weight of the material building the slope, i.e. rocks, soils, vegetation and man- made structures, which act downwards.
(2) Shear strength of materials acting on the potential slip planes.

The relationship of shear strength (*s*) to the casual forces is given by the following formula (Dunne and Leopold, 1978)

$$S = c + (N - P)\tan\Phi$$

where $c =$ cohesion of the components

$N =$ components of weight of the saturated mass acting perpendicular to the plane of failure or slippage ,i.e. $W \cos \beta$,

$P =$ pressure of water within the voids of sliding mass and,

$\Phi =$ angle of internal friction, reflecting degree of interlocking and surface friction.

The safety factor which is taken into consideration to ensure the stability of the slopes depends upon the ratio of forces of resistance (shear strength) to the driving forces.

$$\text{Safety factor } (F) = \frac{\text{Resisting Moments}}{\text{Disturbing Moments}}$$

VIII. LANDSLIDES REMEDIAL MEASURES

A. Modification of slope geometry

(1) Removing material from area driving the landslides (with possible substitution by lightweight).
(2) Adding material to area maintaining stability (counterweight berm or fill).
(3) Reducing general slope angle.

Fig-4- Slope failure and its geometry. Slope destabilization around Devprayag caused due to the widening of NH-58. Yellow Dotted line indicates the recent activation of the slope. House circled by yellow dots was partially buried under the Debris. (Inset) A house damaged due to disturbance of slope during road widening.

B. Drainage

(1) Surface drains to divert water from flowing on to slide area. (Collecting ditches and pipes).
(2) Shallow or deep trench drains filled with free-draining geomaterials (coarse granular fills and geosynthesis).
(3) Buttress couterforts of coarse –grained materials (Hydrological effects).
(4) Vertical (small diameters) boreholes, pumped or self draining.
(5) Vertical (large -diameter) well with gravity draining.
(6) Sub –horizontal or sub vertical holes.
(7) Drainage tunnels, galleries, or audits.
(8) Vacuum dewatering.
(9) Drainage by siphoning.
(10) Electro-osmoting dewatering.
(11) Vegetation planting (Hydrological effect) .

C. Retaining structure

(1) Gravity –retaining walls.
(2) Crib –block walls.
(3) Gabion walls.
(4) Passive piles, piers and caissons.
(5) Cast-in-situ reinforced concrete walls.
(6) Reinforced earth –retaining structures with strip/sheet-polymer/metallic reinforced elements.
(7) Buttress counters forts of coarse-grained material (Mechanical effect).
(8) Retention net for rock slope faces.
(9) Rock fall attenuation or stopping systems (rock trap ditches, benches, fences and walls).
(10) Protective rock/concrete blocks against erosion.

D. Internal slope reinforcement

(1) Rock bolts.
(2) Micro piles.
(3) Soil nailing.
(4) Anchors (pre- stressed or not).
(5) Gravity.
(6) Stone or lime/cement columns.
(7) Heat treatments.
(8) Freezing.
(9) Electro-osmotic anchors.
(10) Vegetation planting (root strength mechanical effect).

IX. DISCUSSIONS

Landslides in terrain and hilly areas is hazardous, if the instabilities are properly not accounted during excavation .rainfall pattern are also responsible for landslides. Hence, it is essential that systematic studies including inputs of geology and geotechnical parameters are taking up during planning stage of projects in order to minimize the environmental hazards. Among the factors that govern the stability of hill slopes, the structural condition of rocks and soils, the gradient of the slope and the amount of water that finds access under-ground play very crucial roles in initiating and controlling landslides, Seismic shocks trigger and accelerate mass-movement on a larger scale but the principal agent is always water. It not only acts as a lubricant, especially if mixed with clays or other slimy or rocks. The mass-movements are manifest in the form of slow movements without breaking into discrete failure planes (creep), comparatively speedy sliding on discrete planes of failures at deeper levels (slumps and slides), or very rapid , almost spasmodic (mudflow). The incidence of landslides is therefore very frequent and their magnitude greater during rainy spells. A remedial measures or two would not be effective in preventing mass-movement .It is always a package of measures that has to be taken, as done successfully in the Teesta valley, Sikkim and the Nilgiri Hills. The strategy for controlling the occurrence of landslides is therefore to stop the entry of water or remove it from the threatened or affected area by a system of surface or subsurface drainage, and by restoring to pumping . The second step is to place buttress wall or retaining wall at the toe of the slope or slide in order to check the movement of the dislocated or destabilized mass .Finally, the damaged slope and its soils should be put under a protective cover of grasses, shrubs and deep –root trees

X. CONCLUSIONS

Although accurate data collection was help to determine new information regarding geological landslide movement, much is still to be learning in order to better prepare for future events. By combining remote sensing applications with onsite remediation and mitigation techniques, we are better enabling ourselves for less damage and disaster in future landslide events. Made remarkable developments in the field of landslide prediction, remediation, and mitigation. As mentioned above, there is still a need for the development of a national landslide data bank under a suitable agency in order to better understand and develop new technology to help avoid both costly and deadly slides in the future

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