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Case Studies of Landslides in India

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Abstract

Landslides (also called «Landslips») are a major threat to the environment, human settlements and infrastructure. They are mostly hill events and cover a wide variety of land forms and processes involving the movement of soil and rock down-slope under the influence of gravity, Landslide phenomenon is experienced in all the hill ranges of India. The Himalayas have been observed to be the scene of most frequent landslide incidents, mainly because Himalayas are a comparatively young mountain system and the rock structure is still weak and fragile. The other hill ranges in India can be grouped in decreasing order of landslide proneness, such as: Northeast hill ranges, Western Ghats and Nilgiris, Eastern Ghats and Vindhyas. Landslides cause extensive damage to houses, roads, buildings, forests, plantations and agricultural fields. The debris originating from landslides results in siltation of streams and rivers, inducing further problems of erosion and floods, Damages to structures, loss of lives as well as properties occur extensively every year as a result of landslides, A majority of landslides are triggered by natural causes, including substantial rainfalls, cloud bursts, earthquakes, etc. In this research paper discuss the problem of landslide disaster management on the basis of two specific case studies. These instances have been selected from areas where the incidence of landslides is high. One case pertains to the Northeastern region, the Naga Hills in Manipur-Nagaland and the other case belongs to the Shiwalik Range in the Northwest of the country.

Keywords: Falling, Sliding, Slopes, Magnitude, Rock and Tendency.

1. Introduction

Landslide may be defined as failure of a slope, mainly under the action of its own weight in which the displacement has both vertical and horizontal components of considerable magnitude. Landslide denotes downward and outward movement of slope-forming materials coin posed of natural rock, soil, artificial fill or a combination of these materials. The moving mass follows anyone of the three principal types of movements, via falling, sliding, flowing or their combinations. The rate of movement may vary from slow to rapid. Every soil mass beneath a slope has the tendency to slide downwards or outwards under the influence of gravity. If the shear strength of soil is adequate to counteract this tendency, the hill slope is stable, otherwise a slide occurs. As per the International Association of Engineering Geology (IAEG), the landslides are simply defined as "the mass movement of rock, debris or earth down a slope" [1].

1.1. Case Studies and Lessons Learnt

Landslides on NW-39 in Manipur-Nagaland the National Highway Number 39 (NH-39) is the only highway, which is motorable, by goods loaded trucks. Since Manipur and Nagaland are land locked States, NH-39 is acting as a lifeline for the area. The Khongnem (Manipur) to Vishema (Nagaland) portion of NH-39 has been witnessing a large number of landslides and sinking of sand, The landslides in Mao area and a large number of sinking portions of road between Mao & Khongnem have often disrupted the free flow of essential goods. It is pertinent to note that the Border Roads Organization (BRO) has declared this portion of NH-39 as a sinking zone. NH-39 owes its origin to an emergency road constructed on a temporary and short-term basis by the British during World War II, keeping in view their immediate needs, without proper survey and study regarding long term impacts. Since there is no alternate route for the essential goods to be brought in, the population of the region has been facing difficulties during landslides. In fact, NH-39 is the lifeline of several Northeastern States. There are a number of perennial landslide sites on this highway, which often block the highway for traffic movements every year. The rainfall in the area is heavy, average annual rainfall being of the order of 2000 mm and the rainy season spreads from May to September. Single day rainfall of over 600 mm and cumulative annual rainfall of the order of 3000 mm are not unusual and trigger large-scale landslides.

1.2. Site Description and Geology of the Area

The area comprises a number of tectonic blocks each with its characteristic tectonic- stratigraphic sequence as given in table 1.1. The area is tectonically active as indicated from the fact that four major thrusts viz. Naga Thrust, Sanis-Chongliyemes Thrust, Philohilna Thrust and Haflong - Disang Thrust within a distance of only 33 km exist in the area. The distance of influence of a thrust is normally several kilometres. These thrusts are so closely located that [hey may act together to cause a combined effect on the area. All the four thrusts go across the highway.

In general, the urea comprises landform younger than tertiary. Geomorphological features are controlled by geological structures and lithological set up. Shale and Sandstone alternations of Disang formation are represented by the break of slopes in the area. The drainage is generally of radial pattern on the top of the peaks which usually consists of thick-bedded sandstone.

Tectoni Blocks	StratigraphicSeque
Assam Shel Facies	Alluviu Namsang an Girujan formati
....	NagaThrust..
Bagti TectonicBlo	Bhuban, Bokabil, Tipam, Girujan, Dihing Formations & UnclassifiedQuater
Grave	
....	Sanis-
Changki TectonicBlo	Laison Jenamand Renji formati
....	Phiphima ....
Piphima Tectonic Bloc	Jenam formati
....	Haflong-Disang ....
	Disang and Laisong

Table 1: Tectono-Stratigraphic Sequences of the Lithounits

1.3. Climate and Rainfall

The climate in the area varies from sub-montane to cool ternperate with temperatures in winter of the older- of 8 degree celsius and summer temperatures going up to 40 degree celsius. The averdge annual rainfall is of the order of 2000 mm and is spread mainly from May to September with scanty rainfall in October: The rainfall in the remaining part of the year is also not uncommon. During winter, frost and clouds of mist are common phenomena.

Material Properties: The slope forming and debris material in the area generally consists of grey shale fragments of various sizes mixed with soil. Rock exposures have been observed at almost all the slide locations where the overlying debris material has slid out. As mentioned above, rock formations are generally composed of grey shales in a moderately weathered condition with frequent joints and figures. The engineering properties of soil aralocation of landslide at km. 2 17 on the National Highway, which is close to Maram village are given in table 1.2.

	Properties	Value
S.No.		
1	Liquid Limit(%) Plasticity Index Cohesion(kN/m^2)	41
2	Angle of Internal Fr(%)ion (Ø) (Degree)	21
3	Soil Classification(as per IS)	8
4		31
5		CI

Table 2: Engineering Properties of Soil at the Landslide Site at km 217 on NH-39

N: Newton, Unit of Force; IS: Indian Standard

1.4. The Landslide

Though NH-39 passes through unstable zones at many places, the road at km 2 14 was not posing any major threat due to sinkings or landslides.

On July 11, 2004 at 6.00 AM, shear cracks were noticed on the road formation for a length of about 270m, followed by sinking. Gradually, the cracks started widening on the road formation, and, sinking up to 1.5m was observed for a length of about 10 m of road stretch.

On inspection of the area on hill and valley sides, severe cracks were found to have developed between km 2 14.24 and km 214.5 and the line of communication was breached. The road stretch kept on sinking from July 11 to 27, 2004. A rainfall of about 3 I0 mm was observed during this period.

1.5. Impact of Sinking/Landslide

Due to this failure, about 80 houses including some permanent buildings experienced severe damage and about 130 families were rendered homeless. Around 300 vehicles carrying essential commodities were stranded on the highway for about 10 days. Though the road was made trafficable, regular sinking of the area during rains has been posing great difficulty, particularly to the heavy vehicles loaded with goods.

1.6. Immediate Measures

Since, high level of deterioration of road formation had already taken place, traffic movements were severely affected. The road formation for single lane traffic was achieved by filling the sinking zone with quarry soils and also restoring the formation cutting in some portion as a temporary measure to allow vehicles to pass.

1.7. Lessons Learnt

The deterioration of formation width has reached alarming proportions and if not attended immediately, would give way during the forthcoming monsoon. This would not only disrupt road communication between the State capitals, viz, Kohima and Inphal, but also badly impact the entire area. Therefore, long-term measures must be adopted to stabilize the landslide.

There is a need to identify surface drainage channels and the spring points on the uphill as well as downhill slopes, and adopt measures to tap the same for quick drainage so that rain water does not accumulate and seep inside.

Most of the water from the springs and rainfall is quickly absorbed by the slope mass, which causes sub-surface water movement and increases hydrostatic pressure in sub-soil. Such water emerges out as spring or sub-surface water channel at some other locations further down the slope and washes away lot of slope material underneath the slope. This phenomenon is known as piping. It is therefore necessary to control sub-soil moisture movement by providing sub-surface drains or trench drains, suitably.

The excessive moisture in the slope mass causes loss of shear strength of the slope material. Efforts are therefore required to reduce percolation of water into the slope, and also to reduce load on the slope due to other structures and overloading of goods carrying vehicles.

The cracks and fissures developed in the area must be sealed to rninimise the percolation of water into the subsoil.

Geophysical instruments should be used to ascertain the depth of bedrocks in the slide area and similar other locations. Such a survey will also help in tracking sub-soil moisture and water channels. This would help in a more realistic design of remedial measures and appropriate planning for future constructions.

We can convert these lessons learnt into practical and useful Do's and Don'ts as given below: **DO'S**

Always be watchful on hill roads and try to note features like cracks on roads or slopes, blocking of drains and seepage points.

Always seal the tension cracks or fissures to prevent percolation of water.

Always try to keep the drainage channels free from obstructions.

Always maintain a gentle gradient on hill roads for smooth traffic movements and to have less vibrations due to overloaded vehicles.

For critical locations, always look for alternate alignments, which should be basedon landslide hazard zonation studies.

Don'ts:

- Do not allow cultivation/grazing on the slide-affected slope.
- Do not provide drains flowing through the slide-affected area.
- Do not put the slided material at the crown of the downhill slope.
- Do not cut or remove the material from the toe of slide.

1.8. Landslides in Shiwalik Wills

Some of the transmission towers of transmission lines connecting thermal plant at Ropar to Gobindgarh are located on top or near the top of small hillocks in the Shiwalik range. These are the low foothills of the Shiwaliks and the small hillocks have steep sides. The lower ranges of Shiwalik hills in Northwest India are composed predominantly of sandstones with varying degrees of cementation. Clays are also found at certain locations in this region. These areas receive scanty rainfall and hence the slopes remain in a state of in saturation over most of the year, normally, such conditions are not conducive for slope failures or landslides. However, many slope instability problems have been experienced in these ranges. It has been observed that some hill-slopes failed generally a few hours after a storm. On some of these failed slopes, towers of high voltage transmission lines are located. The possibility of such failures eventually endangers the stability of the transmission tower foundations, which has resulted in attention being focused on the problem. A typical sketch for the geographic location of these hills and the location of transmission towers is shown in figure 1.1. Slope stability problems were faced at about 15 locations in the area, where high voltage transmission towers of the Punjab State Electricity Board (PSEB) were located. It was observed that some of the slopes were experiencing failures shortly after rainfalls [2].

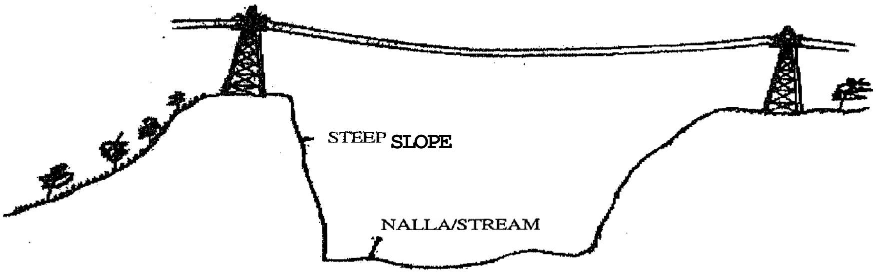

Figure 1: Typical Locations of Transmission Towers in Shiwallik Hills

The stability of slopes is usually calculated assuming that the slope is in a saturated state, which generally represents the worst condition. However, in regions like the present one, the slopes generally remain in a state of instauration. Therefore, the stability of hill slopes was assessed, taking into consideration the time required for the penetration of wetting front in conjunction with the conventional slope stability analysis. This novel approach enabled a realistic evaluation of the safety factor, identification of failure mechanisms and prediction of future stability of the slopes. Remedial measures appropriate to the mechanism of failure were adopted for stabilization of these hill slopes on which transmission towers are located.

1.9. Site Description, Climate and Geology of the Area

The area is made-up of low foothills, with height ranging from 50 to 100 m above the valley floor with steep side slopes, varying from45 degrees to nearly vertical. The hill features are isolated and cut-off by hillside streams, and are thus highly inaccessible. The average annual rainfall is of the order of 1000 mm and occurs mostly during the months of July, August and September. The ground water table is located in the valleys. In most locations, the rock formation consists of sandstone layers, in a few places, formation consists of alternate layers of grey sandstone and red clays. Generally, sandstone beds have greater thickness ranging from 5 to 10 m followed by relatively thin shale layer of 1 to 2m thickness. It is more usual to find the clays near the valley floors. At many locations, both these materials have lost the characteristics of the rock and have weathered down to a more soil like state. The exposed sandstone layers crumble to fine sand even when crushed by hand. The clays materials are over-consolidated and are of low plasticity. At a number of locations, mixed or transition layers occur where sandstone and clays layers are intermixed. The exposed layers show sharp deterioration in strength due to weathering [3].

Material Properties: A number of undisturbed samples were collected from varying depths by cutting blocks of sandstone. The shear strength parameters were evaluated by carrying out direct shear tests under drained conditions. Since most of the samples recovered were in a relatively high state of in saturation, they were allowed to absorb moisture so as to reach saturation, prior to being sheared. The degree of saturation at the end of the direct shear tests ranged from 95-99 percent. The results show that the shear strength, as represented by the effective cohesion and friction parameters varies over a wide range depending upon the extent of weathering the rock sample has undergone. On the basis of the strength parameters, the sand-stones are conveniently divided into three groups, viz. cemented sandstone, cemented sandy soil and sandy soil. Since the ground water table was found to be located in the valleys or at the base of the hill features, the degree of saturation of the materials near the surface was found to be very low.

As already stated, a slope being in saturated state is the worst condition and is most conducive to slope failures or landslides. In the case under study, a degree of instauration prevails initially and the initial pore-pressures are negative. However, as rainwater percolates down into the slope, a zone of saturation builds up as the wetting front advances. If sufficient water becomes available from percolation, a pocket or zone of saturation is formed in the slope area. Thus, maximum possible pore-pressure may prevail over a complete failure surface or a part of it [4].

1.10. Mechanism of Slope Failure

Following observations can be made concerning the mechanism of failure: (i) Local clirnatic condition precludes long duration of rainstorms, hence, deep zone of saturation cannot develop. Therefore, the possibility of deep-seated failure does not exist. (ii) It is likely that the outer 3m of the slope surface get saturated under favourable conditions of percolation and permeability. It has also been found from tests that these layers have been exposed to agreater degree of weathering. Hence they show Iess cohesion. As a result, shallow failures having maximum thickness 2-3m, are likely to occur during or shortly after rainstorrn. (iii) Practical experiences in this area have confirmed the occurrence of a number of shallow failures on the side slopes. (iv) Since the tower foundations are, by and large, located 10 -20 m away from the edge of the slopes, the possibility of their foundation being damaged has been assessed to be low, (v) The likelihood exists that shallow slope failures of the type mentioned in (ii) and (iii) above, may increase in size due to repeated failures at the same place. Remedial measures should ensure that no such retrogressive growth of the shallow failures occurs.

1.11. Remedial Measures

Analysis has shown that slope failures are likely to result from zones of saturation that may develop following the percolation of water. In addition, it has been observed that in a few places, erosion gulleys are formed due to cutting action by water flowing down the slopes. Thus, (he stability of slopes and, thereby, the stability of transmission tower foundations would face danger from the following factors: (i) retrogressive growth of shallow slides that occur along the side slopes. (ii) Unchecked growth and deepening of gulleys that develop due to erosion by flowing water. In some instances, a shallow failure surface might get transformed into erosion gulley, if the terrain conditions permit water to flow down the slide-out area.

Remedial measures focus on controlling both the above mentioned aspects. In order to reduce percolation into the slope, emphasis was placed on adequate drainage of the benches on which the towers are located. Proper grading of the bench to drain the water to a suitable natural outlet nearby and promotion of grass over the bench area have been provided as measures to control and reduce infiltration to the slope. Erosion cuts and gulleys are provided with check dans.

1.12. Lessons Learnt

The stability of a natural slope in unsaturated ground conditions needs to be evaluated, using a combination of the progress of moisture infiltration into unsaturated slope and the conventional slope stability analysis. By juxtaposing results from both these analyses, a realistic evaluation of the factor of safety of hill slope over a wide range of ambient conditions can be made.

As in the present case, while deep-seated failures may be ruled out, slope failures on shallow slip surface were expected to occur.

The mechanism and pattern of failure were found to be dictated by a combination of factors involving rainfall characteristics, pattern of percolation of water into the ground in the slope area and strength variations of slope material due to weathering. As a result of this case study and the lessons learnt as discussed above, the following Do's and Don'ts have been evolved [1-5].

• Always look out for features indicating deterioration or movements on slopes like tension cracks, erosion gullies on slopes or toe cutting at the slopes;
• Look out for any stress in adjoining areas;
• Study the drainage pattern particularly blockings or changes in drainage channels;
• Try to collect as much information as possible on failure plane/features showing distress; and
• I try to co-relate the features with ambient field conditions.

Don'ts:

• Avoid cutting at the toe portion due to excavations/streams
• Avoid loading at the crown portion of slope;
• Avoid concentrated runoff through the body of slope;
• Avoid percolation of water through cracks, broken drains, etc; and
• Avoid cutting / grazing of plants and bushes.

1.12. Landslide Management: Mitigatory Measures

The main mitigatory measures adopted for landslide prone areas are proper land use; drainage correction; reforestation of the areas occupied by degraded vegetation; and above all, creation of awareness among local people. The responsibility to deal with landslides lies mainly with the State Government. The District Administration is the nodal agency on behalf of the State Government, which manages the disaster situation. Especially for landslides, most of the mitigatory actions concern providing short-term relief and rehabilitation to the affected community after the event.

The most important triggering mechanism to reduce damage caused by landslides is to locate development activities on stable ground and utilise the landslide-susceptible areas as open space. This open space may be used for parks, grazing or afforestation. The afforestation programme should be properly planned so that there is very little slope modification in this process. Land use controls can be enacted to prevent hazardous areas from being used for residential buildings or impo tant structures such as roads or transmission lines. Human activities that might activate a landslide should be restricted. The implementation of risk reduction measures must be preceded by locating areas that are prone to slope failures. The landslide hazard map helps planners to determine the level of risks and to take proper decisions regarding avoidance, prevention or mitigation of existing and future landslide hazards. The Central Road Research Institute, Central Building Research Institute and the Geological Survey of India are giving considerable attention to this aspect. They have prepared zonation maps by integrating multiple data bases, which are used for forecasting and forewarning.

Another important mechanism for mass rnovements is the water infiltrating into the overburden during heavy rains and consequent increase in pore pressure within the overburden. In steep slopes, the safety factor of the slope material gets considerably reduced which causes it to move down. Therefore, to prevent this situation, the best natural method is reducing infiltration and allowing excess water to move down without hindrance. As a result, drainage correction is an important mitigation measure that involves maintenance of natural drainage channels in vulnerable slopes. . In the end, it can be stated that houses and roads in vulnerable areas should be avoided or built only according to the prescribed building codes. Strict enforcement of existing rules and enactment of new rules to stop indiscriminate quarrying and mining near vulnerable slopes and deforestation are necessary to reduce and mitigate the hazards. Above all, creation of awareness among the local public is very important to reduce the frequency of the occurrence and the intensity of the impact.

2. Conclusion

It is evident from the first Case Study ofNH-39 (Nagaland) area, which is the lifeline of several North-Eastern States that a number of perennial landslides are occurring on this highway blocking the highway for traffic movements. We have discussed geology of the area, climate and rainfall, material properties, impact of landslides, and immediate measures to manage the disasters. In the end of this case study, we dealt with lessons learnt on the basis of past experiences in the area and prescribed a set of do's and don'ts to reduce and mitigate the impact of landslides.

However, in the second case study, our focus was on slope stability problems in general on hill slopes, which are usually utilized for transmission towers. In this study, we have observed that the problem of sl6pe stability was faced at about 15 locations in Shiwalik Hills where high voltage transmission towers were located. In this regard, some of the slopes were experiencing failures shortly after rainfall.

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