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MAJOR LANDSLIDES IN SIKKIM - ANALYSIS, CORRECTION AND PROTECTIVE MEASURES: A CASE STUDY

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ABSTRACT

The paper presents the case history of two major landslides in Sikkim which had proved to be a source of continual trouble for many years since 1973, causing considerable recurring financial strain on the Border Roads Organisation in order to keep the communications through Highway cuttings in the Sikkim Himalaya are exposed to hazardous landslides of a bewildering variety. Geotechnical investigations have often revealed their complex and violent nature usually associated with high and steep cuttings in immature geological settings, severe river-erosion of toe slopes particularly due to flash floods, deforestation and faulty subsurface and surface drainage conditions during heavy rains. Most landslide cause road blockades thereby badly disrupting the communication system of the region. Some of the important highways, particularly without alternative routes therefore require heavy maintenance inputs. The paper gives an exclusive report on geological, geotechnical field and laboratory investigations of the two selected slides in Sikkim, India. The results of remedial measures suggested and implemented to protect the slope from sliding are discussed in the paper.

KEYWORDS

Landslide, seepage, surface and subsurface drainage, erosion control, subsidence, toe cutting, rock-fall, stability analysis, slope stabilisation, vegetation, horizontal drains.

INTRODUCTION

Most of the landslides in Sikkim Himalaya are associated with the prolonged rainfall, sudden heavy down pour and cloud burst. The landslides occurring in this region are noticed in anthropogenically exploited areas and such landslides are termed as man made landslides. During the construction of road network in the hills of this part of Himalaya, a few of the important scientific and technical facts like natural geological, environmental and climatic conditions are ignored. The modified slope thus creates new geological conditions favourable to landslides formation or reactivation. There was no systematic investigation of the landslides until 1967 excepting for periodical maintenance of the road, as and when the debris collected on the road. During this period, the area which started as a minor debris slide assumed major proportions. The time allowed for planning and implementation of control measures is generally short and detailed investigations are hardly possible in some cases. If all the control measures are not implemented in a single working season, their efficacies always remain doubtful.

Central Road Research Institute, New Delhi carried out the geological and geotechnical investigations and monitoring of two major landslides in North Sikkim Highway in India. An attempt is made to pin-point the reasons for the success of the control measures already implemented and to draw broad-based lessons for future guidance in tackling similar situations in the Himalayan region.

GENERAL GEOLOGY AND HYDROLOGY

The entire territory of North Sikkim Highway lies along the main Himalayan range and the rock formations are sedimentary deposits modified by subsequent tectonic changes. The foothills constitute a linear strip of faulted tertiary sandstone. These tertiary rocks are over-ridden on a thrust plane in an inverted sequence of Gondwana sandstone, Buxa dolomite and quartzite. Daling slate and phyllite, and schist.

The rock types exposed in the landslide affected regions are mostly gneissic in nature and have weathered to form varieties of garnetiferous biotite gneiss and augen gneisses tending towards schist, occasionally impregnated by quartz veins showing pygmatic folding are existing in the region. The attitude of the foliation swings randomly from place to place due to the development of horizontal
and vertical warps. The criss cross development of joint pattern has led to the formation of prismatic blocks, the joints are generally open near the surface and their openness can be attributed to frost action in the snow-fall region. At places biotite schist dominates and makes the region very much susceptible to landslides because of its well developed planes of foliation and soft consistency.

The average annual rainfall in the North Sikkim area is of the order of 3000 mm to 6000 mm and occasional cloud bursts result in very heavy rainfall over a short duration of time, sometimes giving a rainfall intensity of 100 mm per hour or even more. Such cloud bursts have a disproportionately large adverse influence on the stability of hill slopes, resulting in heavy erosion due to the large discharge. Depending upon the magnitude of the erosion, the mass movements assume catastrophic and hazardous nature. The paper describes the results of remedial measures suggested and implemented on the following landslides on North Sikkim Highway.

LANDSLIDE "A"

Natural hazard landslides are most widespread in hilly terrains and are main concern of planners and executors of developmental schemes in these regions. The landslide hazard zonation maps could be of great help in mitigating minimising the risks by this natural phenomenon. Central Road Research Institute, New Delhi carried out such study of hazard zonation in North Sikkim Highway including the landslide "A" area, CRRI Report, 1984.

Landslide "A" has been causing disruption to the movement of traffic since 1962 and has been posing a challenge to the road engineers, Fig.1. The lowest limb of old road has been experiencing maximum instability. During 1966, about 100m uphill of old road, a diversion road was made to bypass this lower limb of the road. Based on the geological and geotechnical investigations, various remedial measures such as lined clutches, trench drains, trench cum surface drains, catch water drains on uphill slopes, sausage walls and slope densification by ballies were recommended. However, a part of these recommendations were implemented, viz. those concerning with surface drainage only. During 1978, the lower limb of the old road got washed away for a length of about 120 meters and was abandoned. The diversion road too has not been satisfactory since the bye-pass stretch which passes through an area grown with cardamom plantation has been affected by creep/mudflow during the rainy season. The diversion road used to settle down in the cardamom field areas during monsoons, Fig.2.

In view of the strategic importance of the North Sikkim Highway (NSH) it was finally recommended that a new bypass alignment should be made after carrying hazard zonation studies on the NSH areas. The factors considered included engineering properties of material constituting the slope, inclination of the slope, hydrology, flow pattern and extent of vegetation, etc. The territory
was divided into three parts mainly according to lithological differences. Each of the above mentioned factors have been examined carefully in the field for each part of the territory and a qualitative rating has been given to each of the factors according to the susceptibility of landslide such as high, medium and low. The qualitative rating for each of the factors then combined and finally divided into three zones with the evaluation of potential stability: Good, Medium and Poor.

The final hazard zonation mapping so arrived gave the basic idea regarding the suitability or usefulness of the area for new alignment of the road. The new proposed alignment of the road was implemented and the constructed road after two years is shown in Fig.3, along with the abandoned old road and the bypass road. The road constructed on the new alignment meets the middle limb of the old road at the top uphill of the slope and is free from any slide problem so far.

**COMPLEX SLIDE "B"

Complex slide "B" consists of two major landslides B-I and B-II. Landslide B-I located on the North Sikkim Highway poses more of a hydrological rather than slope instability problem. The main stream of Nallah Chu-I crosses the road at this location with a peak monsoon discharge often exceeding 44,600 cusecs. The Chu-I is threatened by several slipouts enroute and is fed by a catchment estimated to be on the order of 3.0 sq.km. These slipouts are known to generate a discharge, heavily charged with illsorted debris including massive rolling boulders. The bed of the Chu-I, composed of hard gneissic rock and sloping at 20 degrees, does not pose severe bed erosion problem. However, the left bank runs into a landslide towards the upstream and suffers from a severe threat of erosional instability on the steep slopes downstream, Fig.4. CRRI Report, 1974.
The nallah Chu-I has been the cause of concern to road safety since 1962. Three bridges were constructed over this Chu-I and all were washed away successively in 1966, 1968 and 1970. After that a vented causeway has been provided here. The elevated exposed rock mass on the middle of Chu-I and above the road deflects part of the discharge towards the left bank which is highly prone to erosion. There remains no doubt that the bridge if again built, the left abutment would be in danger due to the rolling boulders during the floods unless the pattern of nallah flow is not trained.

An optimum stabilisation of an unstable slope can be achieved only by an interaction of several measures. Accordingly, following remedial measures were recommended by Central Road Research Institute.

a. Regrading of the elevated rock mass to divert the flow of main nallah away from the left bank and avoid further enlargement of small slips, Fig.4.

b. Shifting of the bridge alignment downstream thereby increasing the height of the bridge abutment on the left bank.

c. To divert the flow of various water courses away from the right bank by providing an intercepting drain to divert most of the discharge towards nallah Chu-I before it joins the road.

d. To provide toe wall on the left bank slope. It will help in stabilising several existing slipouts.

e. Stabilisation of denuded slopes by vegetation growth using coir-netting.

However, the construction of the bridge was delayed because of financial constraints or else. Other remedial measures were also not implemented conjointly before the monsoon i.e. in a single working season. This resulted in toe erosion of left bank slope by nallah Chu-I. Further the left bank slope has got completely denuded due to heavy erosion by sheet flow during monsoon, Fig.5. In addition, the catchment area uphill has also developed into an active slide area, thus aggravating the problem.

LANDSLIDE "B-II"

Landslide "B-II" captured public attention soon after the torrential rains of 1970 had precipitated wide spread damages. The maximum road subsidence reported was about 10m and nearly half a kilometer of its length got affected, Fig.6. After the monsoon of 1973, the downward and outward maximum movements were reported to be 13m and 26m respectively. Border Roads Organisation had built cross-drainage works and some restraining structures. However, due to heavy rainfall in September, 1978, the various protective works have been severely damaged. Monsoon season discharge in Nallah Chu-II attained more than 3000 cusecs and resulted into undercutting. In addition, numerous tension cracks and several spring points have been identified both uphill and downhill of the road.
Central Road Research Institute recommended various remedial measures as given below:

a. Lined catch water drains at various levels over uphill and downhill slope of the road on right bank of Nallah Chu-II were proposed.

b. Lined stepped chutes were provided to discharge the drain water into the Nallah.

c. Lined road side drains and three culverts were recommended along the road stretch.

d. Two retaining walls with plum concrete on uphill and downhill slope were proposed.

e. Wire crated sausage walls were also proposed at various levels over the slide area.

f. Sealing of all tension cracks over the slide area.

More than 75% of these remedial measures were implemented in time and the road at this location was restored for vehicular traffic. A view of corrected slide is shown in Fig. 7.

Fig. 6 View of the landslide 'B-II' and road condition in 1973.

Fig. 7 Panoramic View of Corrected Landslide 'B-II' during 1989.
CONCLUSIONS

Experience in the Himalayan region of Sikkim concluded the following major points:

i. A carefully designed and properly lined drainage system invariably proved to be the most effective measure in preventing or correcting a landslide.

ii. Hazard zonation mapping gives the basic idea regarding the suitability or usefulness of an area for the construction or planning of new projects and road alignment.

iii. It has been realised that remedial measures applied in a piece-meal manner will necessarily confer partial benefits. Hence, all the remedial measures have to be implemented conjointly in a single working season.

iv. Periodical maintenance of protective works subsequent to their implementation is also needed in order to ensure better performance of such corrected works.

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