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Landslides and their mitigation in Gangtok, Sikkim

Jan Otto Larsen[1], Eystein Grimstad[2], Rajinder Bhasin[2], Ashok K. Dhawan[3], Rajbal Singh[3], and S. K. Verma[3]

[1]*Norwegian University of Science and Technology, Trondheim, Norway*
[2]*Norwegian Geotechnical Institute, Oslo, Norway*
[3]*Central Soil and Materials Research Station, New Delhi, India*

ABSTRACT

A study of landslides was carried out around Gangtok, the capital city of Sikkim. Apart from a general survey of the area, detailed investigations were made at Chanmari and Tathangchen as well as along the National Highway 31A. Among various landslides, rockslides predominate and they fail mainly along the foliation planes dipping parallel to the hillside. For example, the Burdang Landslide and Tathangchen Landslide are basically rockslides on schist or phyllite.

To monitor the ground movement at the Chanmari Landslide, six control points were set along the existing drainage channel. The movement of the points is recorded twice a month. Also, four piezometers are set above the landslide scarp to measure the pore water pressure. A similar system with four control points and two piezometers is also established along the main road at the Chanmari Village.

As rainfall is the main triggering factor, control of surface and subsurface runoff is the most important protection measure. The recommended mitigation measures include the construction of drains and retaining walls. It is also recommended to enforce the Government Building Regulations in the landslide-prone areas.

INTRODUCTION

The Indian State of Sikkim (Fig. 1) lies mainly in the watershed of the river Tista. The river and all its tributaries flow through the foothills of the Himalaya where they make deep gorges by extensively eroding the terrain. There are quite many landslides in the Sikkim Himalaya. The geological setting of the area and the high intensity of rainfall are the two controlling factors of their occurrence. Apart from these factors, recent developmental activities, particularly road and building construction have aggravated the incidence of landslides and land subsidence (Mehrotra et al. 1996).

The study focuses on the landslides around Gangtok, the capital city of Sikkim. Apart from a general survey of the area, a detailed study was carried out around Chanmari in the eastern part of the city to understand the failure mechanism of slides and to suggest appropriate mitigation measures. For the purpose of carrying out the stability analyses, the soil samples were tested in the laboratory. Monitoring systems for recording fluctuations of pore water pressure and a plan for investigation of settlement in different parts of the landslide-prone area were also initiated.

GEOLOGY

The Precambrian rocks cover a major portion of the Sikkim Himalaya and are represented by the following four units:

- Everest Pelitic Formation,
- Sikkim Group,
- Chungthang Formation, and
- Kanchenjunga Gneiss Group.

The Sikkim Group of rocks consists of Rangli Schist and Darjeeling Gneiss (Raina and Srivastava 1981). The rocks of the lower metamorphic grades comprising chlorite schist, sericite schist, and quartz schist mainly dominate East Sikkim.

The Chungthang Thrust and the Main Central Thrust (MCT) pass through the East Sikkim Himalaya. They trend due NW–SE and are characterised by crushed and fractured zones. The Chungthang Thrust involves the gneissic rocks of the Chungthang Formation and schistose rocks of the Sikkim Group, whereas the MCT involves the rocks of the oldest Kanchenjunga Gneiss Group (Raina and Srivastava 1981). In addition, one major fault trending NNW-SSE and several other minor faults are also present in this area.

The Rangpo area near the Burdang Landslide consists of metamorphosed arenaceous and argillaceous formations intruded by basic sills metamorphosed to epidiorite and talcose phyllites. A shallow weathered zone comprising sand and silt usually covers the formations. The talcose phyllites have a low friction angle and are very vulnerable. This unit is sensitive to water and can cause creep and slide on the relatively steep slopes prevalent in the area. The other rock

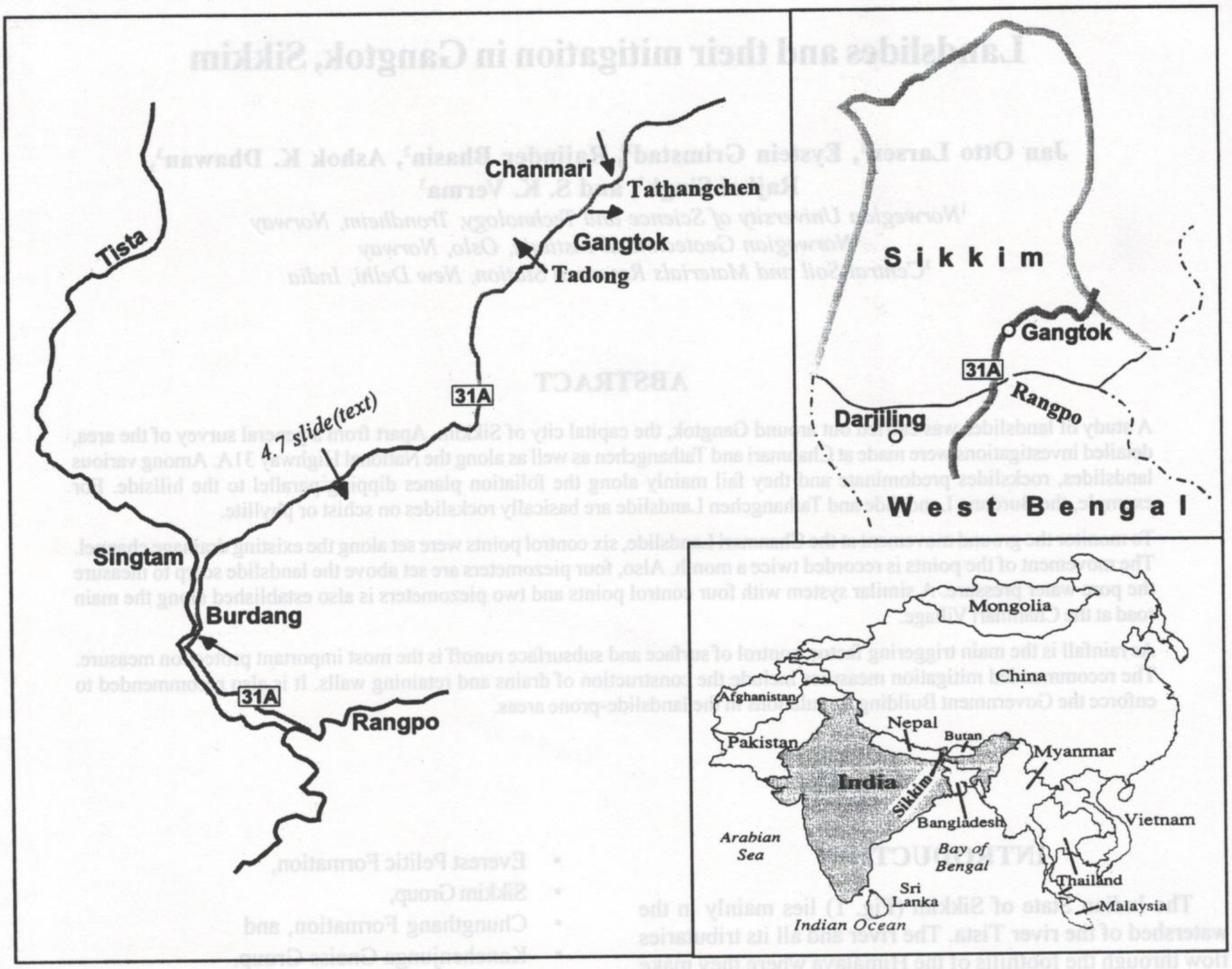

Fig. 1: Location of the study area in Sikkim

types found in the area are black shales, slates, quartzites, and quartz schists with epidiorites, chlorite schists, and talc schists (Mukherjee and Rao 1974).

CLIMATE

Sikkim is located on south-facing slopes of the Himalayan mountain range characterised by a high variation in precipitation rate. The highest amount of precipitation is in the monsoon period (between April and September) while the winter is almost dry.

Gangtok has a meteorological station on the west-facing slope at an elevation of 1,760 m, just 1.5 km away from Chanmari. In spite of 200 m elevation difference and different slope aspect, we have taken this station as a representative one for the landslide area. Since the terrain and elevation have a profound influence on the precipitation and temperature, probably this meteorological station alone does not provide an accurate picture of the weather conditions outside Gangtok. An indication of precipitation gradient can be obtained by comparing the records of the above station with those of the neighbouring station located at Tadong (1,322 m) on the same hillside. Their annual precipitation difference is 544 mm or 123 mm per 100 m.

There is also a significant temperature variation between the summer and winter in Gangtok, but freezing is rare. Hence, there is not much melt water infiltration in the ground in the late winter as in more alpine or arctic regions. The yearly and monthly precipitations in Gangtok are relatively high with an annual average of 3,539 mm. For the peak months of June and July, the "normals" are found to be 603.1 and 649.6 mm, respectively.

The daily precipitation intensity plays an important role in triggering slope instability. The meteorological records show that the maximum daily precipitation can reach 503 mm (in February 1974). The second highest recorded in the last 40 years is 310 mm (in May 1975).

LANDSLIDES

It is noteworthy that among various landslides, rockslides predominate and they fail mainly along the foliation planes dipping parallel to the hillside. For example, the Burdang Landslide and Tathangchen Landslide are basically rockslides on schistose phyllite, chlorite schist, or staurolite-garnet schist. A short description of some of the important landslides is given below.

Chanmari Landslide

A slide at Chanmari occurred on 8 June 1997 after an extraordinarily intense rainfall of 210 mm in four hours, and 615.1 mm in 8 days (Plate 1 and Fig. 2). The landslide moved 15,000 – 20,000 m^3 of debris and destroyed houses and killed people in the lower part of the village. One house located at the crown of the slide was also severely damaged.

The Chanmari Landslide can be divided in two parts. The upper part of the slide that failed in 1997 lies between 1,920 m and 2,000 m, and the lower part (where the village is located on creeping ground) extends between 1,700 m and 1,800 m. The upper slide is in front of an old landslide and contains the weathered material from schistose gneiss mixed with boulders. This is a reactivated old landslide, which started moving in 1960s. The satellite imageries indicate that the slide could have been active even before 1960. The slope affected by the landslide varies between 32° and 35°, whereas the whole slope has an average inclination of 28°.

Part of the Chanmari Village below 1,900 m is on soil from the landslide debris containing clasts of weathered schistose gneiss. Owing to the low friction angle of mica, especially when in contact with water, the whole ground is creeping during the wet monsoon period (when the soil is saturated). The landslide destroyed or damaged many buildings and retaining walls as well as deformed the road pavement. A surface drainage system exists at the village, but the slip surface of the rockslide seems to be significantly below the drains, and hence they are not able to drain out water from the landslide zone.

Tathangchen Landslide

The Tathangchen Landslide is located on an east-facing slope between 1,340 and 1,850 m. It is located on the downhill side of the King's Palace and lies in the same drainage basin as the Chanmari Landslide (Plate 2). It is also a reactivated old landslide along a north–south-directed fault scarp below the Palace.

The area of Tathangchen Landslide is made up of phyllite in the lower part and staurolite-garnet schist in the upper part with a thin residual soil cover. The lower part of the Tathangchen Landslide is on the rock. It is believed that part of the slip surface of the slide is along the steep foliation plane.

The first records of damage date back to 1976–77. During the field investigation, numerous tension cracks were observed both in rock and soil in the area between 1,450–1,550 m. The whole area is creeping with numerous buildings on it. Many buildings have cracked walls, and some cracks are also developed in the Palace building situated near the crown of the landslide.

"Six Mile" Landslide

The landslide is located at a distance of six miles from the "Zero Point" (i.e. the centre of Gangtok) due south along the National Highway 31A. The landslide area was originally a rice field. A ravine has formed in this area after repeated sliding in 1980s. The area consists of phyllite with soapstone and residual soil. The bedrock is exposed in the ravine where a considerable amount of water is flowing. The highway is

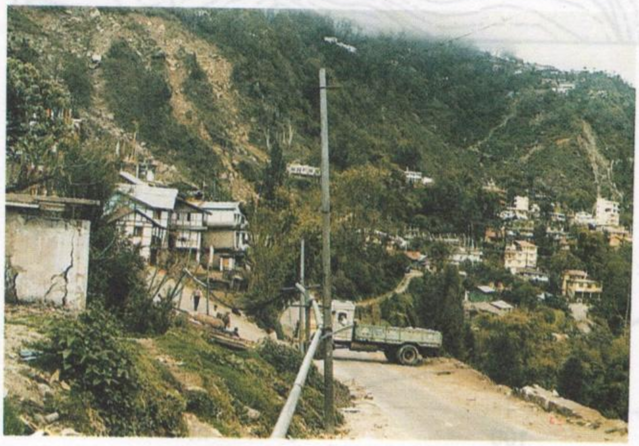

Plate 1: View of the Chanmari Landslide of 8 June 1997

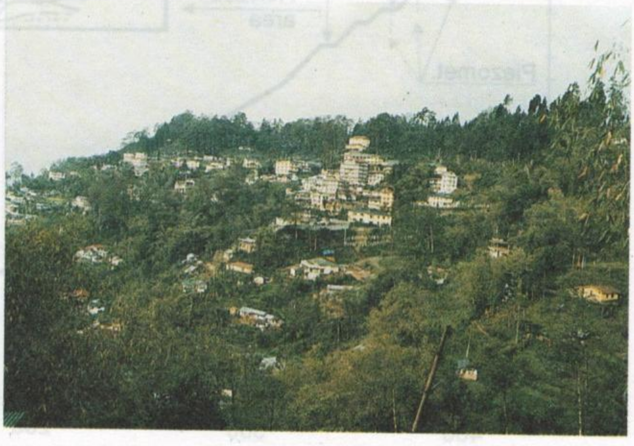

Plate 2: View of the Tathangchen Landslide, Gangtok

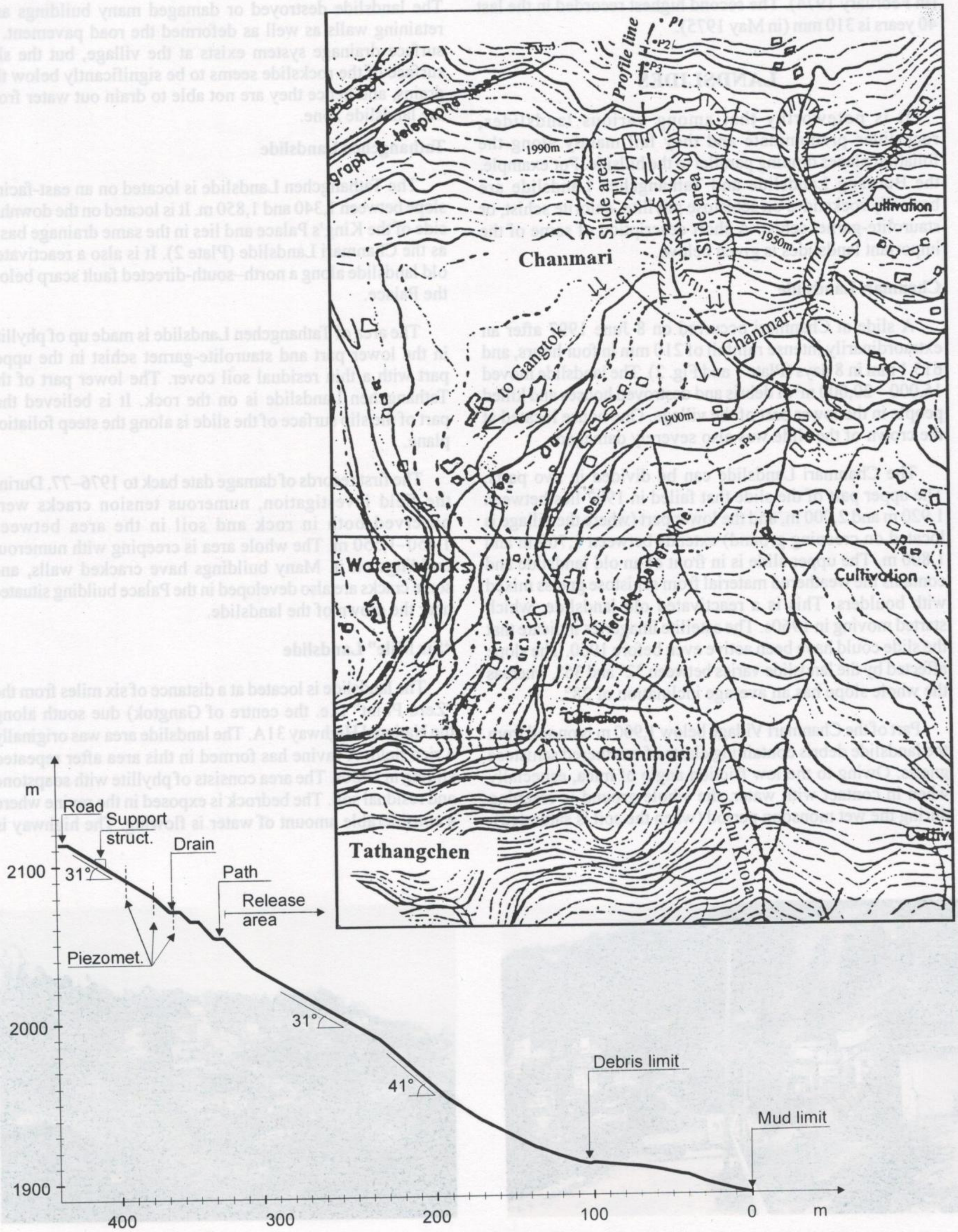

Fig. 2: Longitudinal profile of the western side of the Chanmari Landslide, Gangtok

sinking and the buildings around it are seriously damaged (Plate 3).

Burdang Landslide

Like the Chanmari Landslide, the Burdang Landslide (Plate 4) was also triggered by the rainstorm of 8 June 1997. It has a volume of 100,000–200,000 m^3. Because of the slide, the National Highway 31A (the main connection between West Bengal and Sikkim) was disrupted for a long time, as an enormous mass of debris blocked about 250 m of the road length. Later, a new track was opened temporarily through the slide with bulldozers. But, as the debris and the scarp above were unstable, the road is frequently blocked in the rainy season.

The landslide occurs on a northwest-facing hillslope made up of phyllite and extends between 600 and 725 m. The slope has an average gradient of 36° between the upper scarp and the toe, which is being actively undercut by the river Tista. The slide presumably occurred along the steeply dipping foliation plane of phyllite. These fractures were probably saturated and had lost their shear strength due to high infiltration of water during the rainstorm. The slip surface is undulating and rough (it has the amplitude of 20–50 mm within the length of 1–2 m).

Similar to the Chanmari Landslide, it is also a reactivated old slide, which occurred for the first time in 1960s, when it failed at a lower level but with approximately the same width. At that time, some catch drains of concrete were constructed above the scarp to protect the area from new slides. Later, these drains cracked due to soil creep. Inadequate maintenance of drains caused leakage, which could have been the main triggering factor of the 1997 landslide.

Slide midway between Singtam and Gangtok

The National Highway 31A was totally destroyed by a 200 m wide landslide situated midway between Singtam and Gangtok. The landslide occurred in the monsoon period of 1998 (Plate 5). Part of the slide entered the river and was washed away by the monsoon flood. The other part of the debris is still on the slope. In October 1998, the highway was being maintained on the foundation of the creeping debris. This slide is likely to be reactivated during the forthcoming rainy season.

Plate 3: The sinking part of the National Highway 31A at "Six Miles" Landslide, Tadong

Plate 4: View of the Burdang Landslide by the Tista River

MONITORING AND MITIGATION

After the detailed study of landslides, some monitoring and mitigation activities were undertaken as well as a few recommendations were made for the following major landslide areas.

Chanmari Landslide

Hundred metres below the Chanmari Village at an elevation of about 1,750 m the soil along the Lokchu Khola is rapidly sliding. Catch drains and flood control structures are under construction to regulate the surface water and thus to prevent sliding.

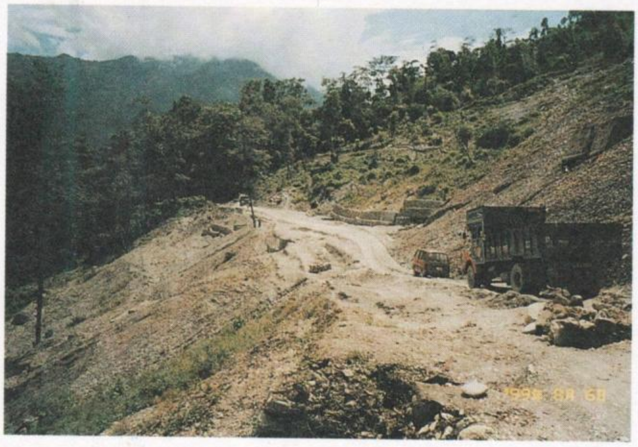

Plate 5: The damaged portion of the National Highway 31A by the landslide of July 1998, midway between Singtam and Gangtok

After the landslide incident of 1997, the Department of Irrigation and Flood Control built a surface drain (Fig. 2) at upper Chanmari (between 2,070 m and 2,090 m). For the slope stability evaluation, it was decided to monitor the ground settlement by a system of six control points along the drainage channel. The movement of the points is recorded twice a month. Also, four piezometers are set above the landslide scarp to measure the pore water pressure. A similar system with four control points and two piezometers is also established along the main road at an elevation of 1,890 m at the Chanmari Village.

Tathangchen Landslide

It is recommended to install two piezometers at an elevation of 1,770 m and to monitor the ground settlement. An appropriate drainage system will be constructed there, based on the monitoring data.

"Six Mile" Landslide

It is necessary to monitor the rate of settlement in various parts of the landslide area including the installation of a few piezometers to evaluate the pore pressure fluctuations. The stability analysis of the landslide should be carried out based on the above data as well as the laboratory study of soil samples. Drainage systems and retaining walls are necessary for the stability of the road.

Burdang Landslide

As the landslide of 1997 has already involved the slope all the way up to the crest, it is least probable that a new large landslide occurs in the near future. The unstable debris cone (which is eroded by the river) and the surface water from above are the two main problems. It is recommended to remove the whole debris cone and rebuild the road by stabilising the slope above the road and controlling the toe erosion. Another alternative is to construct a 300 m long tunnel through the mountain and avoid the landslide zone.

CONCLUSIONS

In Sikkim, mainly the monsoon rain triggers the landslides. Hence, control of surface and subsurface water seems to be the main issue in avoiding landslide problems. It is also necessary to carry out detailed survey, geotechnical investigations, and monitoring of the landslides at least in the critical areas such as highways and villages. It is equally important to enforce the Government Building Regulations in the landslide-prone areas.

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