III−1 Geology and other common factors favoring roadside slope failures in Nepal

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1. BACKGROUND

Due to no alternate route to Kathmandu, the capital city of Nepal, from other densely populated areas, the role of Prithvi Highway and Narayanghat-Mugling Highway (Figure 1) in the nation's transport network is so important that occasional closure of these highways such as due to landslides and floods causes chaos of material shortage in and around the capital. For the last two decades, numerous events of slope failures and resulted closure of traffic especially on the Prithvi Highway have been reported. The disasters, such as in 1993, sometimes became so devastating that the traffic to and from the capital was disrupted for over two weeks. Three highway bridges were swept away and a number of roadside slopes suffered failure. In 1998 through 2001, the highway was blocked for one to three days every year by the debris deposit of the roadside slope failures at different places alongside the Prithvi Highway. Recently in the monsoon of the year 2003, the Narayanghat-Mugling road has been damaged 60% due to debris slides and floods resulting in the need of a reconstruction cost amounting to nearly seven million USD (equivalent to 800 million yen). The report of the Department of Roads shows that the number of failure sites is over 40, most of which are mudflows and debris slides from the hillsides and some are failures of the road itself on the river side. Considering the importance of these highways, therefore, this paper attempts to outline the geological setting of Nepal and introduces a few slope failures alongside the Prithvi Highway favored by weaker geological conditions, heavy precipitation, and improper or inadequate protective measures.

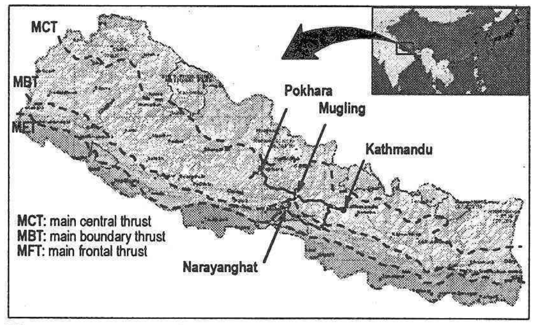

Figure 1: Map of Nepal showing highways to Kathmandu and the tectonic thrust lines.

2. GEOLOGICAL SETTING AND FACTORS INVOLVED

Nepal is situated over three main tectonic planes of thrust of Indian continent against the Eurasian plate. Depending on the location the average annual rate of movement is reported to be 1.5 to 5 cm (Bilham et al. 1998) and nearly half of the horizontal slip is accommodated within the Himalayas. As indicated in Figure 1, the names given to the thrust planes (from south to north) are: 1) main frontal thrust (MFT), 2) main boundary thrust (MBT), and 3) main central thrust (MCT). These thrust planes more or less divide the geology of Nepal. The portion between MFT and MBT is known as the Siwalik Zone, which consists of fluvial sedimentary rocks of Neogene to Quaternary age (i.e., 14 to 1 million years ago) (Upreti, 2001). Similarly, MBT and MCT as boundaries form the zone of Lesser Himalayas, which is made up mostly of unfossiliferous sedimentary and metasedimentary rocks such as shale, sandstone, limestone, dolomite, slate, phyllite, schist, and quartzite. Moreover, the thrust activity has caused folding and faulting of the rock mass with very complicated structures (Upreti, 2001).

The entire length of Prithvi Highway runs over the midlands of the Lesser Himalaya, which vary in altitude from 200 to 2000m and have an average width of 60km (Figure 1). Main rock types found exposed in these areas are schist, phyllite, gneiss, quartzite, granite, and limestone, which are heavily weathered resulting in thick soil formations over the hill slopes. Such soil deposits over comparatively steep slopes are particularly prone to surface failures, especially in deforested areas. Moreover, the state of bedrock mass in the hill slopes is fractured due to the tectonic thrust, which is the main reason for the weak geology in the Himalayas and resulted failure-prone hill slopes.

Similarly, the Narayanghat-Mugling Highway runs across the Siwalik Zone and Mahabharat Range in the Lesser Himalayan Zone to meet the Prithvi Highway at Mugling (Figures 1 & 2). Siwalik Zone consists of geologically young sedimentary rocks such as mudstones, siltstones, sandstones, shale, and conglomerates, which are soft and loosely packed having greater tendency for disintegration. According to Upreti (2001), the conglomerates in this zone are particularly loose and fragile because of low degree of consolidation; the mudstones exhibit swelling behavior and are plastic when saturated; and the sandstones are poorly compacted and weakly cemented, thus being prone to quicker weathering. In addition, these formations are jointed, faulted, and folded, and pass over a number of east-west active thrusts in the Himalayas. Such geological features together with favorable climatic conditions often resulting in heavy rains exceeding an annual value of 2000mm (with 90% during 2-3 months of monsoon period) make the Siwalik Zone highly susceptible to landslides.

Apart from weaker geological conditions, other main factors favoring frequent landslides and slope failures in Nepal are widespread exposure of soft rocks, erosion prone bare mountains, steeper slopes, highly scouring turbulent rivers, existence of relict landslide sites, etc. The natural factors triggering the landslides may be recognized as earthquakes or tectonic activities, monsoon rains, scouring and cutting by rivers, while the human activities responsible for landslide triggering include road and foot trail cuttings, improper quarrying, improper agricultural activities, deforestation, etc.

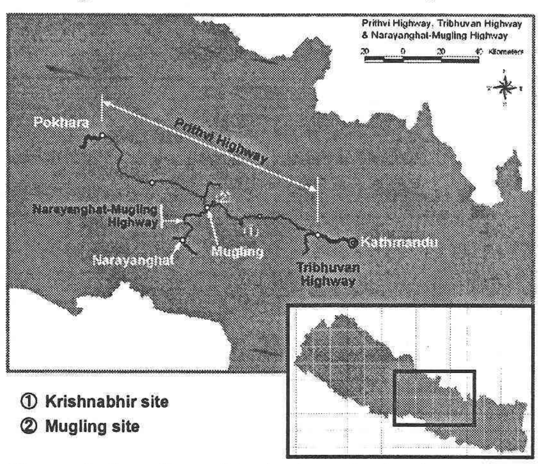

Figure 2: Location of typical roadside slope failures and the highways.

3. TYPES OF SLOPE FAILURE AND TYPICAL SITES

The main failure types along the highways mentioned above can be recognized as being surface failures triggered mainly by gully erosion, debris falls triggered probably by mass movement, rock falls caused by joint failure, creep slides triggered by subsurface mineral decomposition, etc. A two-day observational survey conducted by the authors in July 2003 revealed that there are more than 20 noticeable unprotected or poorly protected landslide sites along the Prithvi Highway. A similar survey was conducted along the Narayanghat-Mugling Highway in November 2003, which revealed that no proper measures have been taken to protect the highway from landslide disasters, and that the most of the recent failures that turned into debris and mud flows were triggered by pore-water pressure generation in the decomposed debris mass near the failure source. The observational survey was mainly focused at five failure sites, of which two sites namely Krishnabhir, a debris fall/slide and Mugling site, a creeping landslide on the Prithvi Highway (Figure 2) are introduced in the following sub-headings.

3.1 *Krishnabhir site*

Krishnabhir site (measuring 400m long and 150m wide near the road) is located at 84km west of Kathmandu alongside the Prithvi Highway. It showed traces of failure somewhere in 1999, which was triggered by a gully erosion of the colluvial deposit on the top of the slope. With the beginning of monsoon of 2000, a massive failure of weathered rock mass in the slope took place resulting in the deposition of the slid mass on the highway and blocked the traffic for two weeks. Reoccurrence took place in the year 2001, and slowly turned into a stabilized deposition of slid mass in the year 2002.

According to Humagain (2001), the major rock types in the Krishnabhir area are phyllite, quartzite, schist, and slate with some calcareous bands. Intercalation of the quartzite and calcareous band in phyllite may be considered to have given rise to instability of the slope. In addition, presence of talc and graphite along the foliation planes seems to have further decreased the shear strength of the rock mass.

The observation of the topography and the exposed rocks reveals that the inherent geological factor involved in the failure site is development of fractures on the slope rock mass due to imperceptible movement of a huge mass that might have failed in a long past (as indicated in Figure 3). A speculation can be made of movement of an old mass in creeping manner causing upper part of the fractured mass to take a form of debris fall. Although borehole investigations need to support this speculation, the depth of mass movement, based on the size of the failure, can be estimated at 30 to 40 meters, and the depth of the debris fall on the top is 8 to 10 meters. Figure 4 explains the speculation made.

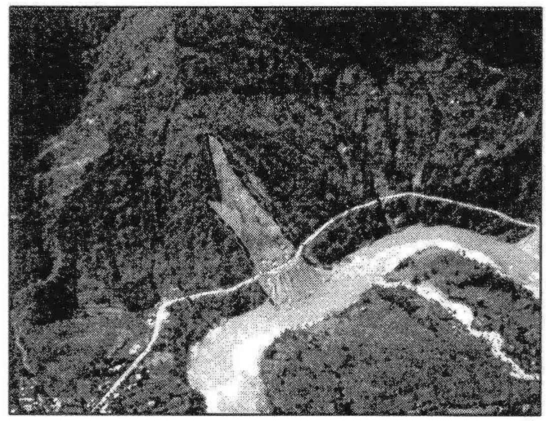

Figure 3: Oblique aerial picture of Krishnabhir Landslide and assumed block of massive failure

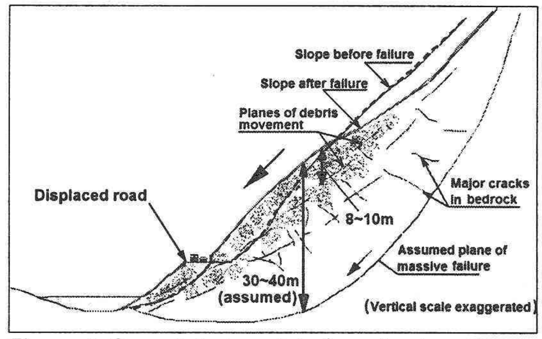

Figure 4: Speculated model of mechanism of Krishnabhir Landslide

3.2 *Mugling site*

About 106 km west of Kathmandu, this landslide site is situated on side of the Prithvi Highway near Mugling. The only traces of the landslide movement at this site are subsidence of about 150m length of the road (Figure 5) and visible scarps near the crown. Seeing the amount of subsidence that has been taking place for more than five years, this failure can be categorized as creeping movement of a mass that might have failed a long time ago. A maximum of about 1.5m subsidence can be seen near the midpoint and 30-50cm depressions can be seen near the edges. The gabion retaining walls along the road edge constructed by the Department of Roads for protecting the road from failure show that this area was recognized as a landslide site at least five years ago (estimated). Observation of the topography as sagging of the slope surface shows that this landslide site is an old deposit of previous failure and subsequent subsurface weathering of rock minerals through the existing plane of failure might be considered to have triggered the creeping landslide, which remains comparatively active during monsoon periods. Based on the subsided length of the road, the depth of the landslide can be estimated at 15-20m.

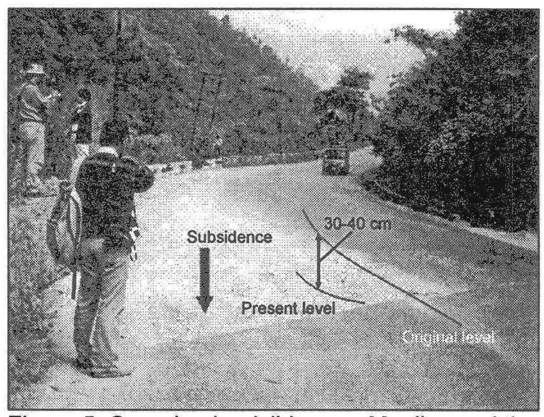

Figure 5: Creeping landslide near Mugling and the road subsidence

4. CONCLUSIONS

Observations along Prithvi Highway and Narayanghat-Mugling Highway in Nepal indicate that no proper and adequate measures have been taken to mitigate or protect the landslides along the major highways that play a significant role in Nepal's economic development. The above two highways run along and across the Mahabharat Range of high mountains and midlands, often known as Lesser Himalayan Zone, which lies over a tectonic thrust line known as main boundary thrust, making the range highly vulnerable to landslides. Despite this geological setting, no appropriate and adequate investigations have so far been carried out in order to identify the failure prone roadside slopes and mitigate the landslide disasters as well as to prevent the highway closure during heavy monsoonal rainfalls. In-depth geological investigations, landslide site identifications, and landslide mappings along the major highways of Nepal are the important steps to protect the transport infrastructures of the nation from frequent landslide disasters.

REFERENCES

Bilham, R., Blume, F., Bendick, R., Gaur, V.K., 1998. Geodetic constraints on the translation and deformation of India: implications for future Great Himalayan Earthquakes. *Current Science*, 74(3), pp213-229.

Humagain, I.R., 2001. Multiple slope failure at Krishnabhir of the Prithvi Highway. *Proc. Int'l Symposium on Geotechnical and environmental Challenges in Mountainous Terrain*, GNESYM2001, Kathmandu, Nepal, pp61-67.

Upreti, B.N., 2001. The physiography and geology of Nepal and their bearing on the landslide problem. "*Landslide Hazard Mitigation in the Hindu-Kush Himalayas*" (eds. Li Tianchi, S. R. Chalise, & B. N. Upreti), pp31-49.