Journal of Nepal Geological Society, 1998, Vol. 18, pp. 329-334

Landslide-dammed lakes: a case study of the Lamabagar and Chaunrikharka landslide deposits, Dolakha and Solukhumbu districts, eastern Nepal

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ABSTRACT

The Lamabagar and Chaunrikharka landslides occurred within the gneisses of the Higher Himalayan lithotectonic unit both about 10 km north of the Main Central Thrust (MCT). Both landslide deposits are in the range of 10 to 100 million m^3 and show an abnormal long stability, which confirms that the big size, the cohesiveness of the material and quick siltation of the impoundment are the most important factors for the longevity of natural dams. The Lamabagar landslide dam (Fig. 1) with a height of about 300 m is standing since more than three generations and the impoundment is completely silted up. The relics of the early postglacial Chaunrikharka landslide dam (Fig. 2) with a former height of about 100 m and the eroded lake sediments of the Gath-Phakting area exposes excellently its inventory. The most probably annually layered bottom-set sediments south of Gath indicate a lifetime of the dam of about 120 years. Terraces within the canyon of Chaunrikharka document a periodical downcutting of the dam. The stable landslide dam of Lamabagar represents a prospective site for a hydroelectric plant of about 30 MW.

INTRODUCTION

The natural damming of rivers by landslides is a prominent phenomenon in the high rugged mountains of the Himalayan region. The dam may last for several minutes or several thousand years. Many landslide dams have failed catastrophically causing major downstream flooding and loss of life as well as damage of infrastructure and hydroelectric plants. This paper gives an introduction to the types of landslide-dammed lakes, their failure and longevity, and presents two case studies of large scale landslide dams within the Higher Himalaya of eastern Nepal.

PHENOMENOLOGY AND TYPES OF LANDSLIDE DAMS

Large scale debris and rock slumps and slides or avalanches (in average bigger than one million m^3) falling into narrow canyons are particularly likely to form high potentially hazardous dams, because they have mostly high velocities that allow complete stream blockage before the material can be sluiced away. Mud, debris and earth flows form a significant percentage of landslide dams (Costa and Schuster, 1988), but most of these dams are not high, and as they are composed mostly of non-cohesive materials, they commonly overtop soon and breach rapidly (Tianchi et al., 1986). Generally, landsliding may cause the development of two types of landslide dams:

- those sliding down a major drainage channel can block side drainage, causing lakes along the lateral margins,
- those much more commonly occurring are sliding perpendicularly across a major drainage from a source on the slope above the channel, damming the primary stream.

MODES OF FAILURE

A dam failure is a complex hydrologic, hydraulic and geologic phenomenon, controlled primarily by

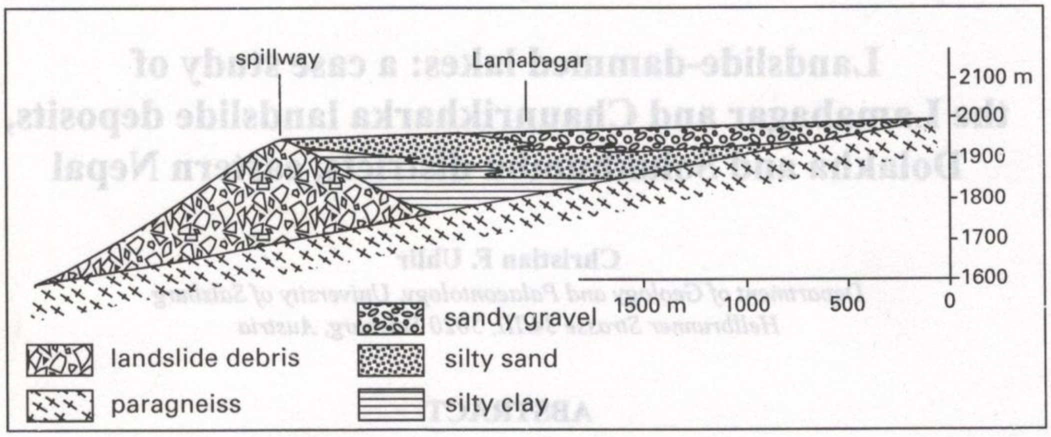

Fig. 1: Idealised longitudinal section of the Lamabagar landslide dam (Dolakha district, eastern Nepal)

the failure mechanism and characteristics and properties of the dam. A landslide dam is made up of unconsolidated or poorly consolidated material and it differs from man-made dams in that it has no water barrier, filter zones and drain zones, it also has no canalised spillway.

Consequently, landslide dams most commonly fail by overtopping, followed by breaching from fluvial erosion. The breach commonly does not erode down to the original river level because many landslide dams contain coarse materials that locally armour the spillway.

Because of the mostly porous material, seepage through the dams potentially could lead to failure by internal erosion. This violent piping and undermining can cause collapse of the dam, followed by overtopping and breaching, as it was described by Heuberger (1975) for the Köfls landslide (Tyrol, Austria), one of the largest landslides within the Alps.

A dam having steep upstream and downstream slopes is susceptible to slope failure because of high pore-water pressure. As large scale landslides occur mostly within areas of active geology, further landslides into the lake can produce a tidal wave, which overtops and erodes the dam.

FACTORS INFLUENCING THE LIFETIME OF LANDSLIDE DAMS

There are three factors that seem to be the most relevant to the longevity of a landslide dam: the rate of inflow, the size and shape of the dam, and the geotechnical characteristics of the material involved.

The rate of inflow to the impoundment and the rate of seepage through the dam control the rate at

Fig. 2: Heavily shattered material with sandy and silty matrix from the Chaunrikharka landslide (Solukhumbu district, eastern Nepal)

which the lake will fill and be overtopped. In case of a slow rising water level, the dams are often stabilised by sand and mud carried into the dams by seepage of water through them. In case of a large mass having smooth slopes like many of such blockages, it provides some degree of protection against failure, especially rapid failure.

If the dam material is of soft, fine grained and saturated material, the shear strength is low and the dam may not be able to withstand the increasing hydrostatic pressure because of the rising water level. Overtopping causes quick erosion of the dam, like at the large scale debris slides at Jarlang and Burang (Dadhing district) in 1954 during the summer monsoon (Uhlir and Schramm, 1997). If the dam consists of mainly large particles or cohesive slide masses, it is more resistant to failure. The spillway is also more resistant against breaching if large boulders armour the outlet.

Of 73 landslide-dam failures, documented by Costa and Schuster (1988), 27% failed in less than one day after the formation, 50% failed within 10 days and 80% failed within 6 months. By contrast, a small percentage can be stable for a long time: the Phoksundo Tal (lake) in west Nepal, formed about 30-40 thousand years before present (Yagi, 1997), is still stable and the Gohna Tal (lake) of northern India held for 78 years (Weidinger and Ibetsberger 1997).

LAMABAGAR LANDSLIDE DAM

The Lamabagar landslide (Dolakha district, eastern Nepal, longitude 86°13′ E, latitude 27°55′ N) occurred within the paragneiss and migmatite series of the Higher Himalayan tectonic unit about 10 km north of the MCT (Schelling, 1992) and originated from the very steep eastern slope along the Tama Koshi. The volume of the dam is around 30 million m^3 and it is nearly 300 m high having an average frontal slope dip of 17°. The dam with a crown elevation of 1970 m asl, having a boulder-armed spillway (Fig. 3), is still stable, for more than three generations (according to witness accounts).

With a length of 3 km and maximum width of 100 m the lake was silted up entirely by river sediments of about 18 million m^3, this would be an enormous amount of water in case of an early dam failure, on the same order as the volume of the Langmoche flash-flood (GLOF) in 1986 within the Solukhumbu district (Vuichard and Zimmermann, 1996). About two generations ago, the dam was covered by a small landslide (according to a witness report). The plains of the entirely silted impoundment are flooded during monsoon and laterally used for farming (Uhlir and Dirnhofer, 1997). The erosion along the spillway seems to be neglegible because of a large amount of rock boulders on the surface. The dam is most probably impermeable to water because of the silty clayey sediments (bottom-set) near the dam-side of the lake.

The area represents a prospective site for a hydroelectric plant. With a potentially usable height of 300 m and a minimum discharge of the Bhote Koshi of around 10 m^3/s, a power of 30 MW can be generated, however, the area seems to be a potentially disastrous (Fig. 1). More detailed mapping of the area was not possible, because it lies within the restricted border area (Fig. 4).

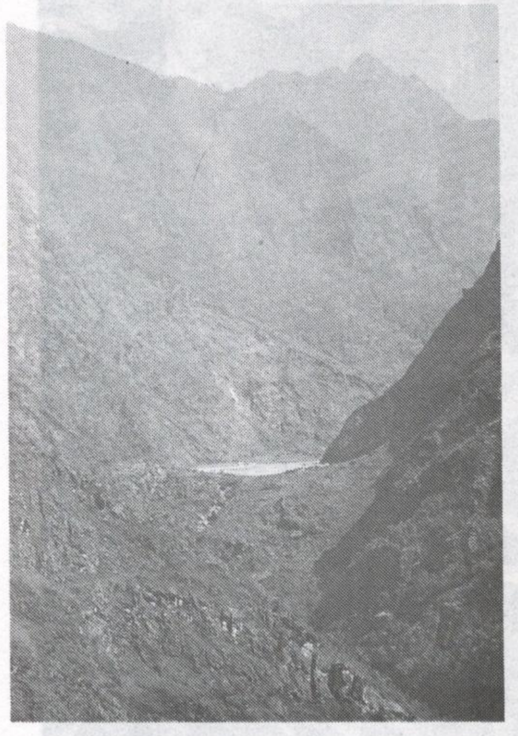

Fig. 3: The Lamabagar landslide dam (Dolakha district, eastern Nepal), showing a boulder armed spillway and a part of the entirely silted impoundment.

SEDIMENTARY INVENTORY OF A LANDSLIDE-DAMMED LAKE

If a landslide dam is stable for a long time, the lakes silt up entirely, forming typical lacustine sediments. At the intake of the main river and its tributaries, delta sediments are formed (front-set), consisting of coarse grained gravel with sandy matrix showing a smoothly inclined diffuse layering and partially cross-bedded.

At the same time, at the deepest point of the impoundment behind the dam, the bottom is filled with silt and clay fraction documenting the seasonal variations of the sediment input by a clear banking. These fine grained sediments can act as a water barrier preventing seepage and they can be transported into the dam, causing impermeability of the dam. Near the intake, uniform silty sand is formed as bottom-set (Fig. 5). Finally, the lake is silted up by top-set sediments consisting of well graded medium to fine grained gravel and sand.

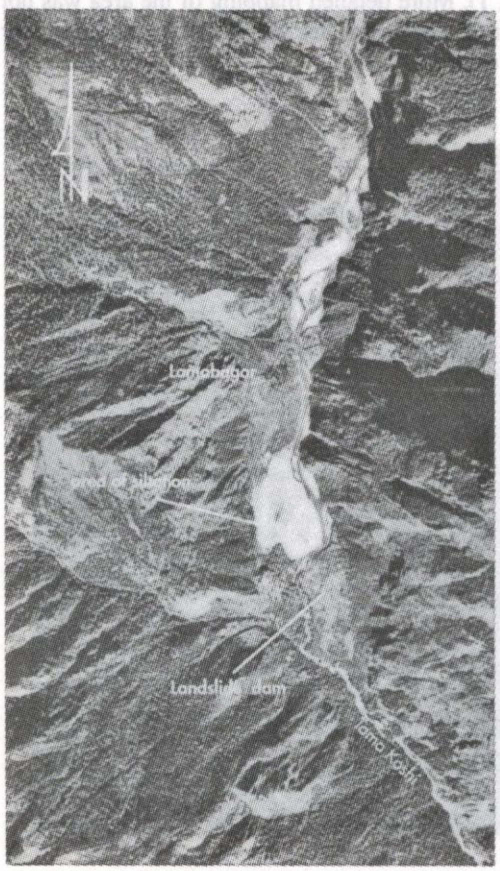

Fig. 4: Aerial photograph of the Lamabagar landslide damed lake (Dolakha district, eastern Nepal).

FAILED LANDSLIDE DAM OF CHAUNRIKHARKA

The postglacial Chaunrikharka landslide (Solukhumbu district, Pharag area, eastern Nepal, latitude 27° 42′ N, longitude 86° 43′ E) or succession of landslides according to Heuberger and Weingartner (1986), lies within basal paragneiss series of the Higher Himalayan lithotectonic unit (Vuichard, 1986), with nearly the same distance to the MCT as the Lamabagar dam. It origins from the western slope of the Dudh Koshi (Fig. 6). First estimation of the dam's volume is on the scale of 100 million m^3 and a height of about 100 m.

The dam consists of typical large scale landslide deposits, consisting of shattered but mainly cohesive rock (Fig. 7). The fine grained detrital material is already changed into clay minerals, which also cause the dam impermeable. This chemical weathering process can be very quick, and can happen within a few years because of a high precipitation of up to 2,500 mm/yr (Zimmermann et al., 1986).

The former Gath lake had an original length of about 5 km (up to Bengkar) and had a maximum width of 800 m containing about 90 million m^3 water. The dam, with an ancient crown elevation of about 2,550 m, is dissected by a 90 m deep gorge nearly to the

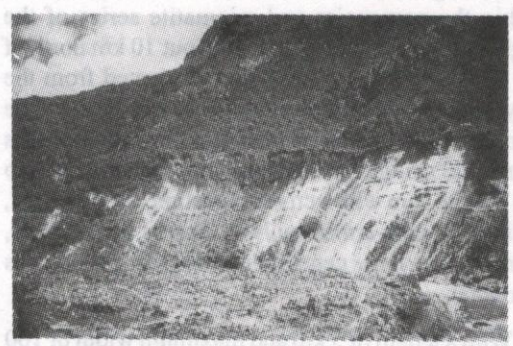

Fig. 5: Bottom- and top-set sediments, covered by landslide debris near Gath (Solukhumbu district, eastern Nepal).

bottom of the landslide deposit, exposing excellently its sedimentary inventory.

The landslide dam failed by overtopping followed by periodic downcutting, evidenced by erosional terraces near Chaunrikharka and river terraces within the gorge. At present, the gorge shows a large amount of still active debris slides, initiated by the Langmoche GLOF (Vuichard and Zimmermann, 1986).

The "varved clays" (bottom-set) of the lake sediments south of Gath (Fig. 7) show a duration of undisturbed sedimentation of around 120 years, if the visible banking can be interpretated as annual cycles (Uhlir, 1997).

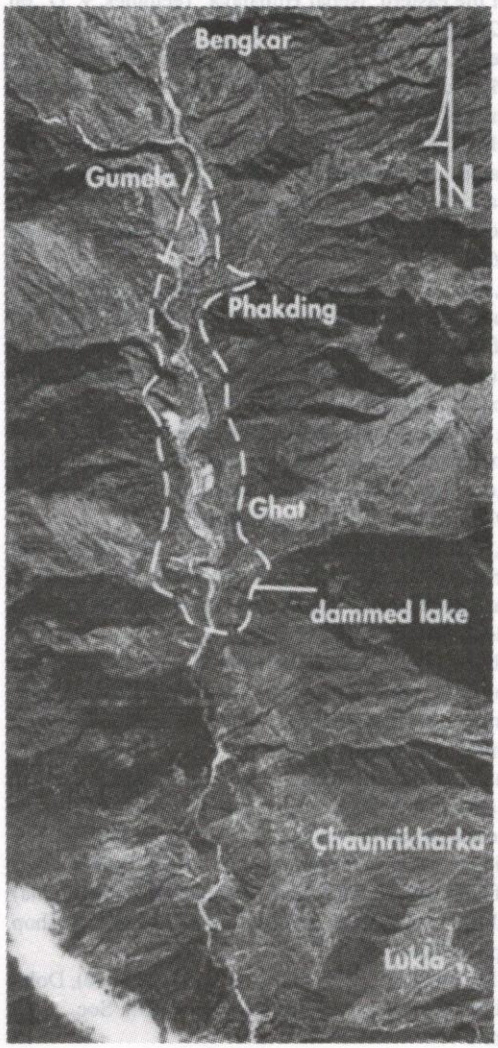

Fig. 6: Aerial photograph of the Chaunrikharka landsllide deposit and sediments of the Gath lake in the Solukhumbhu district, eastern Nepal.

Fig. 7: Relics of the Chaunrikharka landslide, at the eastern flank of the Dudh Koshi, showing typical erosional features (Solukhumbu district).

They are laterally interfingered with coarse grained sediments of torrential debris cones. The tilting and folding of the fine grained lake sediments, interpreted by Panniza (1975) as signs of recent tectonics are typical phenomena of consolidation of silty and clayey sediments due to pressure of the overlying debris cone. The well sorted top-set sediments (medium grained gravel) at Gath show the maximum sedimentation of about 40 m above the current river bed, showing that the lake was entirely silted up after a previous outbreak. A small rockslide of about a half a million m^3, originated from the eastern slope north of Gath, postdates the final stage of sedimentation (Fig. 5).

CONCLUSIONS

Both case studies showed clearly that natural dams, generated by large scale landslides within crystalline rocks deposited within narrow canyons, can be stable for decades and centuries. In both cases, the large mass of the dams could have been a protection against failure. The most important factor influencing the stability is that the displaced material is partially cohesive and consists on its surface mainly of large boulders, armouring the spillway. Further, the susceptivity to water through the dam is low for this type of deposit, because during the movement a large amount of fine rock powder is generated, which starts to transform under wet conditions immediately after the event into clay

Fig. 8: The "varved clays" south of Gath (Solukhumbu district).

minerals, which can prevent piping. But long-time weathering causes a weakening of the shattered landslide debris which slows down the resistance to erosional processes.

ACKNOWLEDGEMENTS

Thanks are due to Mr. A.M. Bassett for reviewing the paper and the Karto Atelier (KTM) of Mr. M. Griesbaum for the preparation of the figures. This paper resulted from a land mapping project (1996) for a HV-power line from Namche Bazar to Lukla (Solukhumbu) and from a hazard mapping project (1997) within the Rolwaling Himal (Dolakha district) for the Austrian NGO ÖKO HIMAL-Salzburg.

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