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LANDSLIDE DAMS: HAZARDS AND MITIGATION

Abstract: SCHUSTER R.L., *Landslide dams. Hazards and mitigation* (IT ISSN 0391-9838, 1993).

Landslide dams commonly occur in steep-walled, narrow valleys in high rugged mountains. They are caused by different types of landslides; high precipitation and earthquakes are their most important causes of initiation.

Most of the dams fail within a few hours or days, but some may last for several thousand years, depending on many factors.

Landslide dams create the potential for flooding both upstream (filling of the lake) and downstream (failure of the dam). Casualties from some of the floods derived from their failure have reached into the many thousands.

Construction of protected spillways, stabilization of lake levels by drainage through gravity and siphon pipes, pumping systems, and tunnel outlets are among the most commonly used methods of improving the stability of landslide dams.

KEY WORDS: Landslide dam, Landslide, Corrective measures.

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Le dighe da frana avvengono normalmente nelle aree montuose, in valli profonde e dai versanti ripidi. Esse sono provocate da diversi tipi di frane, i cui principali agenti d'innesco sono le piogge intense ed i terremoti.

La maggior parte delle dighe cede dopo poche ore o giorni dalla loro formazione, ma alcune durano diverse migliaia di anni. Ciò dipende da diversi fattori. Le dighe da frana creano un alto potenziale di inondazione sia verso monte (per il riempimento del lago di sbarramento) che verso valle (collasso della diga). Le perdite umane a causa di alcune inondazioni derivate da collassi di dighe da frana hanno raggiunto le migliaia di individui.

Per migliorare la stabilità di queste dighe, si ricorre a misure come la costruzione di canali di sfioro, la stabilizzazione del livello del lago per mezzo di condotte a gravità ed a sifone, i sistemi di pompaggio e le gallerie di sfioro.

TERMINI CHIAVE: Dighe da frana, Frana, Interventi.

INTRODUCTION

Landslide dams significantly affect the morphologies of valleys by changing valley gradients and often causing significant deposition of fine sediments in the impoundments. Catastrophic failures result in hazards to people and development in many parts of the world. The factors must be considered when locating engineered structures, such as hydroelectric dams, in valleys in which landslide dams have occurred or have the potential to occur (SCHUSTER & COSTA, 1986).

Because they lack controlled outlet structures, nearly all landslide dams eventually are overtopped by their impounded lakes, and many have failed catastrophically, causing major downstream flooding (COSTA & SCHUSTER, 1988). Casualties from some of these floods have reached into the many thousands. The worst known case occurred in 1786 when a landslide dam of the Dadu River in Sichuan Province, China, breached; the resulting deluge extended 1,400 km downstream, drowning as many as 100,000 people (Li, 1989). In another extreme example, the 1841 failure of a 200 m high landslide dam of the Indus River, India, caused a disastrous flood of water and mud that swept away hundreds of villages and towns with great numbers of casualties (MASON, 1929).

CHARACTERISTICS OF LANDSLIDE DAMS

Geomorphic settings

Steep-walled, narrow valleys in high rugged mountains commonly are the sites of the highest landslide dams because (1) these valleys are subject to slope failure and (2) their cross sections are such that they require relatively small amounts of material to form blockages. Mountain valleys can also be the sites of low dams; a common case is the formation of a low dam on a river by a debris flow or mudflow issuing from one of its tributaries.

Type of landslides that cause damming

The vast majority of landslide blockages is cause by (1) rock and soil slumps and slides, (2) rock and debris avalanches, and (3) debris flows and mudflows. A few have been caused by slope failures in sensitive clays and by rock and earth falls.

Causes of dam-forming landslides

The most important causes of initiation of landslides that form dams are abnormally high precipitation (including rapid snow melt) and earthquakes. Landslide damming is so common following major earthquakes that "dammed

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lakes" are specifically noted under Intensity XII of the Modified Mercalli Intensity Scale of 1931 (WOOD & NEUMANN, 1931).

Size and geometry

Landslide dams range in height from only a few meters to hundreds of meters high. The highest (570-m) landslide dam known to have occurred during historic time was caused by the 1911 earthquake-triggered 2.5 km^3 Usoy rock avalanche, which dammed ther Murgab River in the south-central U.S.S.R., forming 53-km-long Sarez Lake (BERG, 1950). The Usoy landslide dam is more than twice as high as the world's largest constructed dam, 300-m-high Nurek earth-fill dam, also in the south-central U.S.S.R.

For each landslide dam more than 10-20 m high, there are many that are only 1-2 m high. Most of the low dams fail within a few hours or days and many of them are never observed. A high percentage of these small dams are formed by debris flows from tributary streams.

Landslide dams commonly differ from constructed earth-fill dams in material volume and in the relationship between height of the blockage and its width (dimension parallel to the stream). Landslide dams commonly are much wider than earth-fill dams of the same height, and thus involve considerably larger volumes.

MODES OF FAILURE OF LANDSLIDE DAMS

Landslide-dammed lakes may last for several minutes or for several thousand years, depending on many factors, including: (1) volume and rate of water and sediment inflow to the newly formed lake, (2) size and shape of the dam, (3) geotechnical properties of the geologic materials comprising the dam, and (4) rates of seepage through the blockage. Failure of landslide dams depends on resistance to erosion, either at the dam surface from surface-water runoff, or inside the dam due to seepage. Landslide dams consisting of large rock fragments or cohesive particles resist failure more successfully than dams containing large percentages of soft rock or unconsolidated geologic materials. Landslide dams composed mainly of soft, low-density, fine-grained, or easily liquefied materials are hazardous because they are relatively susceptible to erosion.

Because of the lack of erosion-resistant outlets, landslide dams commonly fail by overtopping followed by rapid surface erosion, progressing from the toe of the dam toward the crest. Because of "self armoring" of the eroding outlet (a process involving removal of fine material by the water, which leaves coarser, erosion-resistant fragments in the channel), the breach in many cases does not erode down to the original river level. For this reason, smaller lakes after dam failure.

In a few cases, landslide-dammed lakes have formed natural spillways across adjacent bedrock abutments. These spillways prevent overtopping and possible breaching of the dams. This process may occur where the toe of the landslide dam is higher than the surface of the adjacent bedrock abutment.

FLOODS FROM LANDSLIDE DAMS

Landslide dams create the potential for two very different types of flooding: (1) upstream (backwater) flooding as the lake fills and (2) downstream flooding due to failure of the dam. The threat of loss of life from upstream flooding is minimal, but property damage can be substantial. Important facilities, such as hydroelectric power plants, may become inoperable (SCHUSTER & COSTA, 1986). Although less common than upstream flooding, downstream flooding from failure of landslide dams is generally a more serious problem. A catastrophic example of downstream flooding resulted from the A.D. 1515 failure of a rock-avalanche blockage of the Brenno River, a tributary of the Ticino River, in southern Switzerland. The flood engulfed the city of Biasca with an explosive surge of debris and water that continued down the Ticino valley for 35 km to Lake Maggiore on the Italian border (MONTANDON, 1933, pp. 295-296). About 600 people were killed by the flood.

ENGINEERED CONTROL MEASURES

The simplest and most commonly used method of improving the stability of a landslide dam has been the construction of protected spillways either across adjacent bedrock abutments or over the dam itself. An example of a carefully engineered spillway across a landslide dam was constructed by the U.S. Army Corps of Engineers on the 1959 Madison Canyon landslide dam, Montana, U.S.A. This 75 m wide spillway designed for a discharge of 280 m^3/s and velocities that would only slowly erode the rock sizes that comprised the surface of the landslide dam (HARRISON, 1974).

In a few cases, large-scale blasting has been used to excavate new stream channels through landslide dams. This technique was used in 1964 to open a channel through a 15-million m^3 landslide that dammed the Zeravshan River in Tadzhikistan, U.S.S.R., upstream from the ancient city of Samarkand (Engineering News-Record, 1964). The dam was 220 m high, 400 m long, and more than 1800 m wide. Two blasts, utilizing 250 tons of explosives, successfully excavated 230,000 m^3 of landslide material and formed a 40 to 50 m deep drainage channel through the blockage.

Other methods of preventing overtopping of landslide dams by stabilizing lake levels include drainage through gravity and siphon pipes, pumping systems, and tunnels outlets and diversions. A system of siphons and pumps was used to drain the lake formed by the damming of the Adda River in northern Italy by a large rock slide/rock avalanche in 1987 (GOVI, 1989). In 1988, flow through the Adda River was diverted through two bedrock tunnels (6.0 and 4.2 m in diameter) constructed through the left abutment of the dam.

REFERENCES

BERG L.S. (1950) - *Natural regions of the U.S.S.R.* Macmillan, 435 pp.

COSTA J.E. & SCHUSTER R.L. (1988) - *The formation and failure of natural dams.* Bull. Geol. Soc. Amer., *100,* 1054-1068.

ENGINEERING NEWS-RECORD (1964) - *Russians blast through landslide dam,* 7 May, p. 24.

GOVI M. (1989) - *The 1987 landslide on Mount Zandila in Valtellina, Northern Italy.* Landslide News, Japan Landslide Soc., *3,* 1-3.

HARRISON A. (1974) - *Madison Canyon slide mass modification by the U.S. Army Corps of Engineers.* In: VOIGHT B. (ed.) - *Rock mechanics. The American Northwest.* Third Intern. Congress on Rock Mechanics, Intern. Soc. Rock Mechanics, Penn. State Univ. Coll. Earth Sc. Experiment Station Spec. Publication, 138-143.

LI TIANCHI (1989) - *Landslides: extent and economic significance in China.* In: BRABB E.E. & HARROD B.L. (eds.) - *Landslides: extent and economic significance.* Proceedings of 28th Intern. Geol. Congress, Symposium on Landslides, Washington, D.C., 17 July, 271-287.

MASON K. (1929) - *Indus floods and Shyok glaciers.* Himalayan Journ., *1,* 10-29.

MONTANDON F. (1933) - *Chronologie des grands eboulements alpins, du debut de l'ere chretienne a nos jours.* In: *Materiaux pour l'Etude des Calamites.* Soc. Geogr. Geneve, *32,* 271-340.

SCHUSTER R.L. & COSTA J.E. (1986) - *Effects of landslide damming on hydroelectric projects.* Proceedings of 5th Intern. Congress of the Intern. Assoc. Engin. Geol., Buenos Aires, 20-25 October, *4,* 1295-1307.

WOOD H.O. & NEUMANN F. (1931) - *Modified Mercalli Intensity Scale of 1931.* Seismol. Soc. Amer. Bull., *21* (4), 277-283.