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RISK-REDUCTION MEASURES FOR LANDSLIDE DAMS

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MODES OF FLOODING RESULTING FROM LANDSLIDE DAMS

Landslide dams cause two types of floods: (1) upstream (backwater) flooding as the impoundment fills, and (2) downstream flooding resulting from failure of the dam. Although less common than upstream flooding, downstream flooding is usually more serious and may be catastrophic. The world's worst landslide-dam disaster occurred when the 1786 Kangding-Louding earthquake in Sichuan Province, China, triggered a huge landslide that dammed the Dadu River (LI, 1989). After 10 days, the landslide dam breached, creating a flood that extended 1400 km downstream and drowned 100000 people. A similar disaster resulted from the 1513 failure of a rock-avalanche dam of a tributary of the Ticino River in southern Switzerland. The resulting flood engulfed the city of Biasca with a surge of debris and water that continued down the Ticino valley for 35 km, drowning about 600 people (MONTANDON, 1933). These are examples of extreme events that probably could not have been prevented even with modern technology. However, mitigative measures can prevent the failure of most landslide dams, or at least can reduce the severity of flooding.

CHARACTERISTICS OF FAILURE OF LANDSLIDE DAMS

A landslide dam and its impounded lake may last for a few hours or for thousands of years, depending on (SCHUSTER, 1995):

- rate of inflow to the lake, which is based on size of the drainage basin upstream from the dam and on the amount and rate of precipitation into this basin;
- size and shape of the dam. Obviously, a high dam will take longer to fill than a low one, and a wide dam will be more resistant to failure upon overtopping than will a narrow one;
- physical character of the materials that comprise the dam;
- rate of seepage through the dam.

Longevity of landslide dams whose impoundments have filled depends mainly on resistance to erosion, either at the dam surface from surface flow or in the interior of the dam from internal erosion (piping). Landslide dams consisting of large rock fragments or stiff clays are more resistant to erosion than dams comprised of high percentages of unconsolidated, easily eroded geologic materials.

Some landslide dams do not fail quickly; it often requires months, or even years, for them to fail. An example is the 1985 200x10^{6} m^{3} Bairaman River landslide in Papua New Guinea that formed a 200 m-high dam, which required 16 months to fill. This dam breached within one day after overtopping (KING *et alii*, 1989).

MITIGATIVE MEASURES TO PREVENT FLOODS FROM LANDSLIDE DAMS

When the possible failure of a landslide dam threatens people or property either upstream or downstream, immediate measures must be taken either to stabilize the blockage or to prevent lake levels from reaching dangerous elevations. These mitigative measures can be accomplished by one or more of the following:

1) *Diversion of inflow water before it reaches the impounded lake* - This can be accomplished by diverting water from the stream into upstream reservoirs or irrigation systems. Although only a temporary measure, diversion may slow the filling of the impoundment enough to allow implementation of other, longer-term measures.
2) *Temporary drainage from the impoundment by pumps or siphons* - Rising lake levels can be controlled temporarily by means of pumps or siphons that harmlessly raise water over the low point of the dam crest. This is usually a short-term (less than 1-2 years) measure that provides time for more extensive, long-term solutions.
3) *Construction of an erosion-resistant spillway* - The most common method of stabilizing a landslide dam is to construct an erosion-resistant open-channel spillway either across the dam or across an adjacent abutment. Thus, when overtopping occurs, flow is controlled by the spillway, as is the case for emergency spillways on engineered dams. In addition, an excavated spillway lowers the elevation of the dam crest, thus reducing the extent of upstream flooding. However, spillways are not always successful in preventing breaching and downstream flooding; they sometimes fail due to retrogressive erosion (i.e., headward erosion from the spillway outlet to its intake) caused by high-velocity outlet flow. To prevent erosion by minimizing flow velocity, the

spillway should be wide and shallow. It should be lined with erosion-resistant materials (commonly rip rap), especially at the outlet. Often “check dams” are installed along steeper grades of the spillway to prevent erosion. Spillways that fail due to erosion may be partially successful because they have limited the total volume of the impoundment, thus reducing total discharge even if the dam breaches entirely.

4) Open-channel spillways across the landslide dam commonly are excavated by bulldozers; however, draglines, backhoes, explosives, and hand labor all have been used. Because the most hazardous landslide dams often occur in areas of rough topography, it may be difficult to transport the necessary equipment and personnel to the site. An access road may have to be constructed.

5) *Drainage tunnel through an abutment* - A long-term method of preventing overtopping and breaching of a landslide dam is construction of a diversion tunnel through an adjacent dam abutment. Because large landslide dams commonly occur in mountain canyons, they usually have bedrock abutments; thus rock-tunneling methods commonly are used. Usually, tunnel construction begins at the downstream portal and progresses upstream. It may be necessary to prevent the rising lake from encroaching on construction of the upstream portal of the tunnel by pumping and/or siphoning or by construction of a cofferdam. In some cases, it may be necessary for the tunnel to enter the lake below the level of the lake surface, thus requiring construction of a lake tap.

6) *Drainage conduit through the dam* - Occasionally, a drainage conduit (commonly a culvert, pipe, or lined tunnel) is installed through the landslide dam to limit the elevation to which the lake can rise. To allow time for “dry” installation of the conduit, pumps and/or siphons can be used to to slow the rate of filling of the lake. In some cases, a drainage conduit has been used as a temporary solution, followed by a permanent diversion tunnel through an adjoining abutment.

CASE HISTORIES UTILIZING THE ABOVE MITIGATIVE MEASURES

MADISON RIVER, MONTANA, U.S.A., 1959

In 1959, the earthquake-induced, 21×10^6 m^3 Madison Canyon rock slide formed a 70 m-high blockage of the Madison River, southwestern Montana. Fearing an overtopping failure of the natural dam, the U.S. Army Corps of Engineers quickly constructed an open-channel spillway across the crest of the rock-slide dam. This 75-m-wide spillway was designed for a discharge of 280 m^3/s and velocities that would only slowly erode the rock-fragment size that comprised the landslide dam (Harrison, 1974). In the 45 yrs since construction of the spillway, erosion has degraded the lake outlet only 6-7 m (Schuster, 1995). Nearly all of this erosion occurred in the first 5 yrs, an indication that the impoundment, Earthquake Lake, will enjoy long life as a geomorphic feature.

VISOTCHITZA RIVER, YUGOSLAVAIA, 1963

In February 1963, the 4×10^6 m^3 Zavoj landslide blocked the Visotchitza River, forming a 35 m-high natural dam that impounded a 30×10^6 m^3 lake. The dam and lake posed a severe hazard to populated areas downstream (Anagnosti *et alii*, 1989). Inflow to the lake was estimated at 26 m^3/s, a rate that necessitated construction of a temporary open-channel spillway because there was not time to complete a permanent diversion tunnel before overtopping of the dam occurred. Long-term mitigation was accomplished by means of a 600 -long, 2.5 m-diameter tunnel excavated through the left sandstone/marl abutment starting at the downstream end. The below-lake-level intake for the tunnel was accomplished by a lake tap, which was constructed by blasting through the last 10 m of rock.

VAIONT RIVER, FRIULI-VENEZIA-GIULIA REGION, NORTHERN ITALY, 1961

In 1961, a 2.3 m-long diversion tunnel was constructed along the north bank of Vaiont Reservoir during early stages of reservoir filling. The tunnel was constructed as a precautionary measure because of concern that a landslide might block flow through the reservoir. a possibility posed by cracks that were forming along the the south valley wall during early stages of filling (Kiersch, 1964; Selli & Trevisan, 1964). In October 1963, as the lake neared capacity, a 270×10^6 m^3 rockslide from the south valley wall blocked the reservoir, thus damming the Vaiont River. The precautionary diversion tunnel was located ideally in that neither portal was buried by the slide. The tunnel still serves as the outlet for the Vaiont River through the landslide dam.

ZERAVSHAN RIVER, TAJIKISTAN, U.S.S.R., 1964

In 1964, large-scale blasting and bulldozing were used to excavate an open-channel spillway across a 15×10^6 m^3 landslide that dammed the Zeravshan River upstream from the ancient city of Samarkand (Engineering News-Record, 1964). The landslide dam was 220 m high, 400 m long (perpendicular to the river), and 1800 m wide. Two blasts, utilising 250 tons of conventional explosives, excavated a 40 to 50 m-deep open-channel spillway across the blockage.

NORTH FORK TOUTLE RIVER, STATE OF WASHINGTON, U.S.A., 1980

The May 1980 eruption of Mount St. Helens in the Cascade Range of the State of Washington created a 2.8 km^3 rock slide-debris avalanche that swept 24 km down the North Fork Toutle River. The debris avalanche dammed the North Fork and tributaries, impounding four landslide-dammed lakes, the largest being Spirit Lake. A government panel concluded that the 70-m-high Spirit Lake dam would fail catastrophically if overtopped. Using a mathematical dam-break model, Swift & Kresch (1983) predicted a flood of catastrophic proportions from this possible failure.

As Spirit Lake slowly rose, in November 1982 the U.S. Army Corps of Engineers installed a temporary pumping system to prevent overtopping. The 20-pump facility, with a maximum capacity of 5 m^3/s, pumped water through an 1112 m-long by 1.5 m-diameter buried pipe placed across the dam crest (Sager & Chambers, 1986). Four possible alternatives were considered for a permanent solution of the Spirit Lake hazard: (1) a permanent pumping facility, (2) an open-channel spillway. (3) a buried conduit, and (4) a diversion tunnel through the bedrock right abutment. Each alternative was evaluated in regard to (1) stability in relation to the debris avalanche, (2) stability in case of volcanic or seismic activity, (3) efficacy of construction, (4) environmental disturbance of the site, and (5) cost. Based on these considerations, a 2.5 km-long, 3.4 m-diameter tunnel was driven through the volcanic-ridge right abutment immediately west of Spirit Lake. A somewhat smaller lake (Coldwater Lake), which was impounded at the mouth of a tributary of the North Fork Toutle River by the same debris avalanche, was controlled by an open-channel spillway excavated by the U.S. Army Corps of Engineers across the bedrock right abutment of the dam (MEYER *et alii*, 1986; SCHUSTER, 1989).

SPANISH FORK RIVER, UTAH, U.S.A., 1983

The April 1983 Thistle debris slide (volume: 22x10^6 m^3) in central Utah was a reactivation of a prehistoric landslide in sedimentary rocks caused by above-normal spring snowmelt. The debris slide blocked the Spanish Fork River, forming 63 m-high Thistle landslide dam, which impounded a lake with a volume of 74x10^6 m^3 (HANSEN & MORGAN, 1986). Upstream flooding submerged the village of Thistle, destroying 15 businesses, 10 homes, and railroad switching yards.

Soon after the landslide occurred, officials of the State of Utah decided to drain the lake as soon as possible to prevent overtopping and probable failure of the natural dam. A temporary 2.4x3.0 m-diameter drainage tunnel, 145 m long, through the right sandstone abutment, was completed on 4 May 1983 to prevent overtopping of the dam (BISCHOFF *et alii*, 1984; HANSEN & MORGAN, 1986). Shortly thereafter, it was decided to drain the lake by means of a permanent diversion tunnel through the right abutment. The plan included: (1) a 670 m-long, 4.25-m-diameter, horseshoe-shaped tunnel excavated through the right abutment at stream level, and (2) a 5 to 6-m-diameter vertical shaft from lake level to the upstream terminus of the tunnel A lake tap was accomplished by excavating a channel between the lake and the shaft; this channel was deepened sequentially as lake level was lowered. The resulting product was a deep, narrow channel extending from the riverbed to the back wall of the shaft (BISCHOFF *et al*., 1984). The lake was completely drained by the end of 1983.

ADDA RIVER, LOMBARDIA REGION, NORTHERN ITALY, 1987

On 28 July 1987, the 35x10^6 m^3 Mount Zandila (Val Pola) rock slide–rock avalanche formed a natural dam 30-60 m high, 1200 m long (normal to the river), and 2500 m wide on the Adda River in northern Italy (CAMBIAGHI & SCHUSTER, 1989; GOVI, 1999). Because of the danger of breaching of the landslide dam upon overtopping, 80000 people living downstream were evacuated during August, and a 2 km-long open-channel spillway was dug across the crest of the dam. As a temporary measure, during September-October, pumps and siphons were installed to reduce overflow through this channel and to drain Lake Val Pola, a function that was completed by the end of 1987.

Soon after the landslide occurred, construction by drilling and blasting began on two diversion tunnels through the granite left abutment. These tunnels, with diameters of 5.0 and 4.2 m, are 3.5 km long, and have a total discharge capacity of 540 m^3/s (CAMBIAGHI & SCHUSTER, 1989). Because Lake Val Pola had been drained by pumping and siphoning before tunnel construction began, no lake tap was needed. In addition, timing of construction of the tunnels was not as critical as at most other landslide dams because there was little or no danger of the tunneling operation being inundated during construction. The tunnels became operational in 1988.

PISQUE RIVER, NORTHERN ECUADOR, 1990

On 2 January 1990, a 3.6x10^6 m^3 landslide, triggered by irrigation wastewater, dammed the Pisque River 30 km northeast of Quito, creating a 58 m-high natural dam (ASANZA *et alii*, 1992; PLAZA-NIETO *et alii*, 1999). The dam was composed of easily erodible, uniform silty sand derived from volcanic tuff, with fragments and blocks of soft tuff, sandstone, and breccia; thus, the dam was considered to be very susceptible to erosional failure upon overtopping. Consideration was given to pumping water over the dam to prevent overtopping by the lake, but this was not feasible because pumps large enough for such an operation were not available in Ecuador.

Officials decided to limit the volume of the lake short of overtopping by bulldozing a deep open-channel spillway across the dam, thus lowering the dam crest. By 6 January, construction began of an access road over rough terrain to allow heavy equipment to reach the site. On 16 January, the access road had been completed and two bulldozers reached the site. It required 7 days to complete the channel under dangerous working conditions. The completed channel was 11 m wide, 9 m deep, and 100 m long. It was not lined because of lack of time to procure and place erosion-resistant rip rap. Because the landslide materials offered little resistance to erosion, it was recognized that this channel spillway would not prevent erosional failure of the dam. Instead, its function was to reduce the severity of the expected flood by limiting the depth of the lake.

One day after lake level rose to the channel invert, spillway erosion had caused a breach at least 50 m wide and 30 m deep, draining more than 60 percent of the lake at a peak discharge of 700 m^3/s. Cultivated terraces, a small bridge, and two houses were destroyed by the flood. Had the spillway not been constructed, a larger flood undoubtedly would have occurred, and losses would have been much greater.

PAUTE RIVER, SOUTHERN ECUADOR, 1993

On 29 March 1993, the 30x10^6 m^3 La Josefina landslide formed a 70 m-high blockage of the Paute River, 25 km downstream from the city of Cuenca in southern Ecuador (CHAMOT, 1993; PLAZA-NIETO & ZEVALLOS, 1999). The impoundment soon inundated upstream homes, farm land, and roads. It was not possible to obtain pumps in Ecuador that could handle the 50-150 m^3/s inflow to the lake; thus, a decision was made to excavate a 23 m-deep open-channel spillway across the dam crest. By 8 April, bulldozers were working 24 hrs a day to reach design depth of the spillway before the lake rose to the working level. However, because of heavy rains, the lake rose faster than anticipated, and the excavated slope was in danger of failing. On

13 April, excavation efforts were abandoned at a depth of 18 m because of risk to bulldozer operators and equipment. Final excavated volume was 150000 m^3.

At this time, the opinion was that, after overtopping, erosion would be fairly rapid for the first few meters, but later would slow due to "self armoring" by material too coarse to be eroded from the spillway. Thus, partial breaching with a maximum flow of <3000 m^3/s, not a catastrophic flood, was predicted. However, early on 1 May, retrogressive erosion reached the channel entrance, and the spillway failed, leading to a catastrophic flood estimated at 8250 m^3/s (CANUTI *et alii*, 1999). The flood inundated homes, farm land, and transportation facilities before entering Amaluza Reservoir of the Paute Hydroelectric Project, 50 km downstream; an estimated $4x10^6$ m^3 of sediment was deposited in the reservoir.

CHIN-SHUI RIVER, YIN-LIN COUNTY, WEST-CENTRAL TAIWAN, 1999

Large landslides dammed the Chin-Shui River at Tsao-Ling in west-central Taiwan in 1862, 1941, 1942, and 1979 (KAWADA, 1943; CHANG, 1984). Most of these landslide dams failed catastrophically, causing major damage downstream. On 21 September 1999, a M 7.3 earthquake in central Taiwan caused another large (volume: ~$125x10^6$ m^3) landslide at the Tsao-Ling site, again damming the Chin-Shui River, and impounding a l5 km-long lake that reached a volume of $46x10^6$ m^3 (KAMAI *et alii*, 2000; SCHUSTER & THRONER, 2000; CHIGIRA *et alii*, 2003). As the lake rose, a decision was made by the Taiwan government to resort to mitigative measures to prevent catastrophic failure of the dam, as had happened at the earlier landslide dams at this site. A permanent solution to maintain the reservoir at a level less than that for overtopping would have been the construction of a trans-basin bedrock outlet tunnel approximately 5 km long (SCHUSTER & THRONER, 2000). However, this option was soon discarded because of its high cost and because it would have taken 2 yrs or more to construct.. Instead, an open-channel spillway approximately 4 km long was constructed across the crest of the dam. At critical locations along this channel, the channel walls were lined with rip rap to prevent erosion. In addition, on the downstream slope of the Tsao-Ling landslide dam, where flow velocities would be the greatest, small check dams were constructed in the spillway channel to further insure against erosion. Thus far, the spillway is performing satisfactorily; however, there is still a slight possibility of dam failure due to overtopping and erosion resulting from heavy rainfall. For this reason, so that the downstream population can be forewarned of the potential hazard, LI *et alii* (2002) have carried out a one-dimensional flood routing study for the valley downstream based on possible catastrophic failure of the dam.

YIGONG RIVER, EASTERN TIBET, CHINA, 2000

On 9 April 2000, a $300x10^6$ m^3 debris avalanche dammed the Yigong River in eastern Tibet (HAN, 2003). The natural dam, which was 60-100 m high, 2.5 km long, and 2.5 km wide, impounded Yigong Lake (ZHU *et alii*, 2003). Following the advice of geologists and engineers, a spillway channel was dug across the dam by Chinese Army troops in an attempt to prevent dam failure. By 7 June, rapidly rising Yigong Lake attained a volume of $2.9x10^9$ m^3. On 19 June, the dam failed catastrophically by overtopping and rapidly eroding the newly dug spillway channel. The 45 m-deep outburst flood lasted 6 hrs, damaged a highway downstream in Tibet and destroyed many bridges. Because of adequate warning, there were no casualties in Tibet. However, the flood rushed downstream into the valley of the upper Brahmaputra River in northern India where 94 people were killed, 2.5 million were left homeless, and highways and railways in seven provinces of northern India were paralyzed (ZHU *et alii*, 2003).

CONCLUSIONS

The cases presented illustrate the difficulties in mitigation of hazards from landslide dams. In some cases, open-channel spillways constructed across landslide dams have not been successful because of retrogressive erosion. However, even for failure of a dam with a constructed open-channel spillway, these surface drains have reduced both upstream and downstream flooding by limiting the amount of water impounded. Spillways constructed across bedrock abutments usually provide long-term mitigation.

Bedrock diversion tunnels constructed through an abutment have almost always been successful as long-term remedial measures for landslide dams. However, they are expensive and usually require considerable construction time. The extra time needed to construct such tunnels can be gained by utilizing upstream diversion, pumps and/or siphons, temporary conduit drains (through the dam), or open-channel spillways (across the dam). In some cases, the inlets for these tunnels are constructed below lake level, requiring construction of lake taps.

REFERENCES

ANAGNOSTI P., CAVOUNIDES S. & PETRIDES G. (1989) - *Landslides in southeastern Europe: extent and economic significance*. In Brabb, E.E. & Harrod, B.L. (eds.), Landslides: extent and economic significance, Proc., 28th Int. Geological Congress, Symp. on Landslides, Washington, D.C.; 381-385.

ASANZA M., PLAZA-NIETO G., SCHUSTER R.L., YEPES H. & RIBADENEIRA S. (1992) - *Landslide blockage of the Pisque River, northern Ecuador.* In Bell, D.H. (ed.), Landslides, Proc., 6th Int'l. Symp. on Landslides, Christchurch, **2**: 1229-1234.

BISCHOFF J.A., ESSEX R.J. & FREEMAN S.T. (1984) - *Lake Thistle – evaluation of lake tap alternatives*. Tunneling Technology Newsletter, Washington, D.C., National Research Council, **45**: 1-7.

CAMBIAGHI A. & SCHUSTER R.L. (1989) - *Landslide damming and environmental protection – a case study from northern Italy.* In Proc. 2nd International. Symp. on Environmental Geotechnology, Shanghai, **1**: 381-385.

CANUTI P., FRASSONI A. & NATALE L. (1999) - *The 1993 La Josefina rockslide and Rio Paute landslide dam, Ecuador – 2) Failure of the Rio Paute landslide dam*. In Sassa,

K. (ed.), Landslides of the world, Kyoto, Kyoto Univ. Press: 359-361.

CHAMOT P. (1993) - *El deslizamiento La Josefina en el valle del Rio Paute, Cuenca, Ecuador.* Report to the United Nations and Swiss Red Cross, Zurich.

CHANG S.C. (1984) - *Tsao-Ling landslide and its effect on a reservoir project.* Proceedings 4th Int. Symp. on Landslides, Toronto, **1**: 469-473.

CHIGIRA M., WANG W-N., FURUYA, T., & KAMAI T. (2003) - *Geological causes and geomorphological precursors of the Tsaoling landslide triggered by the 1999 Chi-Chi earthquake*, *Taiwan*. Engineering. Geol., **68**: 259-273.

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

HADLEY J.B. (1964) - *Landslides and related phenomena accompanying the Hebgen Lake earthquake of August 17, 1959*. In The Hebgen Lake, Montana, earthquake of August 17, 1959, U.S. Geol. Survey Prof. Paper, **435**: 107-138.

HAN Z.S. (2003) - *Large-scale landslide-debris avalanche in Tibet, China, (1) April-June 2000 Yigong landslide, Tibet, China*. Landslide News, international newsletter of The Japan Landslide Soc., February, 14/15, 22-23.

HANSEN D.C. & MORGAN R.L. (1986) - *The 1983 landslide dam at Thistle, Utah.* In Schuster R.L. (ed.), Landslide dams: processes, risk, and mitigation, Am. Soc. of Civil Engrs. Geot. Spec. Publ., **3:** 59-83.

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, 3rd Int'l. Congr. Rock Mechanics, Int. Soc. Rock Mechanics, Pennsylvania State Univ. College Earth and Mineral Sciences Experiment Sta. Spec. Publ., 138-143.

GOVI M. (1999) - *The 1987 landslide on Mount Zandila in the Valtellina, northern Italy.* In Sassa K. (ed.), Landslides of the world, Kyoto, Kyoto Univ. Press, 47-50.

KAMAI T., WANG W.N. & SHUZUI H. (2000) - *The landslide disaster induced by the Taiwan Chi-Chi earthquake of 21 September 1999*. Landslide News, international newsletter of the Japan Landslide Soc., June, **13**: 8-12.

KAWADA S. (1943) - *Study of the new lake formed as a result of the 1941 earthquake in Taiwan (Formosa).* Bull. of the Earthquake Research Institute, Tokyo Imperial University, **21**: 317-325 [in Japanese].

KIERSCH G.A. (1964) - *Vajont reservoir disaster, geologic causes of tremendous landslide accompanied by destructive tidal wave.* Civil Engrg., American Society of Civil Engrs., **34(3)**: 32-39.

KING J., LOVEDAY J. & SCHUSTER R.L. (1989) - *The 1985 Bairaman River landslide dam and resulting debris flow, Papua New Guinea.* Quart. Jour. Engrg. Geol., **22**: 257-270.

LI M-H., HSU M-H., HSIEH L-S. & TENG W-H. (2002) - *Inundation potentials analysis for Tsao-Ling landslide lake formed by Chi-Chi earthquake in Taiwan.* Natural Hazards, **25(3)**: 289-303.

LI T. (1989) - *Landslides: extent and economic significance*. In Brabb, E.E & Harrod, B.L. (eds.), Landslides: extent and economic significance, Proc., 28th Int'l. Geol. Congr. Symposium on Landslides, Washington, D.C., 271-287.

MEYER W., SABOL M.A. & SCHUSTER R.L. (1986) - *Landslide-dammed lakes at Mount St. Helens, Washington.* In Schuster R.L. (ed.), Landslide dams: processes, risk, and mitigation, American Soc. Civil Engrs. Geot. Spec. Publ. **3**: 21-41.

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

PLAZA-NIETO G., & ZEVALLOS O. (1999) - *The 1993 La Josefina rockslide and Rio Paute landslide dam, Ecuador, 1) The La Josefina rockslide.* In Sassa K., Landslides of the world, Kyoto, Kyoto University Press: 355-358.

PLAZA-NIETO G., YEPES, H. & SCHUSTER R.L. (1999) - *Landslide dam of the Pisque River, northern Ecuador*. In Sassa K. (ed.), Landslides of the world, Kyoto, Kyoto University Press: 362-365.

SAGER J.W. & CHAMBERS D.R. (1986) - *Design and construction of the Spirit Lake outlet tunnel, Mount St. Helens, Washington*. In Schuster R.L. (ed.), Landslide dams: processes, risk, and mitigation, American Soc. Civil Engrs., Geot. Spec. Publ. **3**: 42-58.

SCHUSTER R.L. (1989) - *The 1980 eruptions of Mount St. Helens: engineering geology*. In Galster R.W. (ed.), Engineering Geology in Washington, Wash. Div. Geol. & Earth Resources Bull., **78** (2): 1203-1228.

SCHUSTER R.L. (1996) - *Landslide dams – a worldwide phenomenon*. Journal Japan Landslide Soc., **31 (4):** 38-49 [in Japanese].

SCHUSTER R.L. & THRONER R.H. (2000) - *Technical review of Tsao-Ling landslide mitigation efforts*. U.S. Bureau of Reclamation report to the gov't. of Taiwan, Taipeh, 24 Feb., 35.

SELLI R. & TREVISAN L. (1964) - *Caratteri e interpretazione della frana del Vaiont.* Giornale di Geologia, Annali del Museo Geologico di Bologna, Series 2, **32**: 7-104.

SWIFT C.H., III, & KRESCH D.L. (1983) - *Mudflow hazards along the Toutle and Cowlitz Rivers from a hypothetical failure of Spirit Lake blockage*. U.S. Geol. Survey Water-Resources Investigation Report 82-4125, 10.

WEN B., WANG S., WANG E. & ZHANG J. (in press) - *Characteristics of rapid giant landslides in China*. Landslides, International Consortium on Landslides, Kyoto.

ZHU P.Y., WANG C.H. & WANG Y.C. (2003) - *Large-scale landslide-debris avalanche in Tibet, China, (2) formation of an exceptionally serious outburst flood from a landslide dam in Tibet.* Landslide News, international newsletter of The Japan Landslide Soc., February, 14/15, 23-25.