Flow Slides in Uzbekistan: Overview and Case Studies

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Abstract

Paper describes in brief spatial distribution of the landslide-prone areas in Uzbekistan, temporal evolution of these phenomena during last 60 years and organization of the landslide monitoring in in the country. Special emphasis is given to flow slides in loess and clayey often triggered by the prolonged low-frequency seismic vibrations of the distant deep Hindu Kush earthquakes. Three typical case studies of such flow slides that occurred in the recent years are presented and their evolution and motion characteristics are described. Seismometric measurements performed at the source zone of the Achiyak landslide prove that the vibration frequency of the deep Hindu Kush earthquakes coincides with natural frequency of the loess blanketing the slopes in the foothill areas of Uzbekistan that cause resonance effects. Multi-stage evolution of large flow slides some of which transform into mud flows that can last from several days to several years is described by examples of the Khandiza and the Otbokarsai flow slides.

Keywords

Loess • Monitoring • Flow slide • Mudflow • Blockage

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Introduction

A systematic study of landslides and their monitoring in Uzbekistan began in 1958. It was performed, first, by the special Landslide engineering-geological party, and, since 1994, by the State Hazardous Geological Processes Monitoring Survey (hereafter named Survey) that consists of 7 regional stations located in the foothill areas of Uzbekistan.

The State monitoring system is divided into 2 parts—the general regular regional monitoring and the long-term comprehensive stationary observations at reference sites. The main task of the Survey is to provide information, alert and warn public and authorities about the possible activation of hazardous geological processes close to settlements and economical facilities in order to arrange security measures timely.

Regional monitoring is carried out in the spring seasons (from mid-February till end of May) in high alert mode. Observations are conducted at 500–570 sites located in the landslide-prone areas in the Eastern part of Uzbekistan with mountainous or hilly relief (Fig. 1). Each year, before the start of the spring, the Survey issues warning information about possible manifestations of dangerous exogenous processes in the territory. If signs of slope processes activation are detected, the Survey issues an order to the local administration to start on-site monitoring.

To protect people during the landslide-prone period temporary evacuation to a safe place is recommended, as a priority measure. During this period, particular attention is paid to monitor the climatic conditions to predict large-scale slope failure. Manifestations of all types of hazardous geological processes are recorded in the daily regime. In addition, according to the results of the on-site monitoring, special 1:25,000–1:10,000 warning maps for linear structures, for recreation areas and for endangered settlements are compiled and updated annually.

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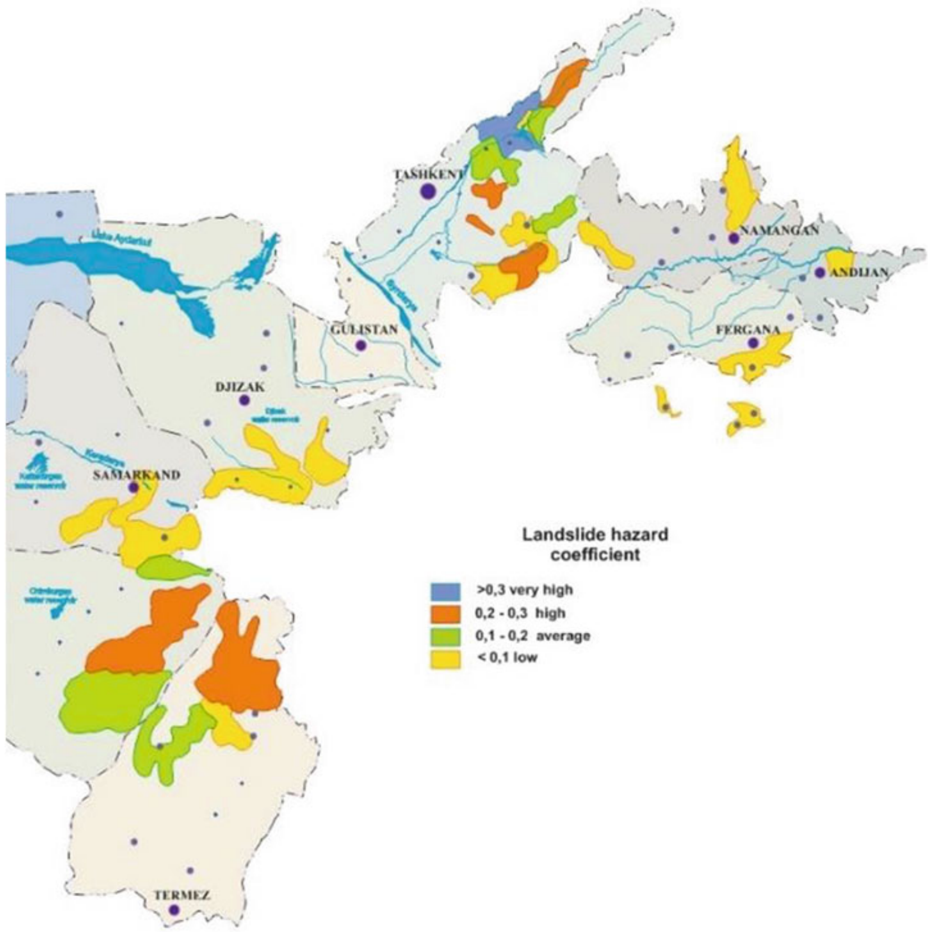

Fig. 1 Landslide hazard zoning map of Eastern Uzbekistan. Notice that such zoning has been performed not over the entire territory but at some particular areas

General Landslides Statistics

The total number of landslides with volume more than 1 thousand m^3 that were formed or reactivated in Uzbekistan during a 60-years long period is about 3300–3500. If we consider smaller events there have been more than 12,000 cases. Over decades, the largest number of landslides occurred in 1958–1970 (991 cases), and in 1991–2000 (934 cases), much more than in 1971–1980 (238 cases), in 1981–1990 (245 cases), and in 2001–2019 (from 340 to 545 cases). The largest yearly number of landslides was recorded in 1969 (721 cases), in 1987 (191); in 1993(350), in 1994 (135), in 1998 (142), in 2005 (185) and in 2012 (72) (Fig. 2). 340–350 sites have been affected by large landslides exceeding 10^5 m^3 in volume and 120–130 events exceeded 1 million m^3. The largest historical event in Uzbekistan is the Atcha block slide (41.012° N, 70.184° E) about 800 million m3 in volume (Niyazov 2009).

No clear and justified tendency of the increase or the decrease of the mean annual number of dangerous exogenous processes have been identified. Many modern landslides are just the reactivation of the older (prehistoric or ancient) and often larger landslides. These secondary landslides are of various scales and types. Such interrelations complicate the assessment of the landslides' frequency at a large extent (Niyazov and Nurtaev 2014).

1270–1400 householders appeared to be in the landslide prone zones in different periods of time. By 2015–2019, their number decreased to 40–80. During last 30 years new villages have been built, and about 2,000 families have been relocated there, and, thus, the number of householders that require resettlement decreases every year.

Landslides caused by anthropogenic impact in different years ranged from 40 to 60% of their total amount. The flow slides, which number exceeds 250, though being relatively rare, in comparison with landslides of other types, represent the most dangerous type of slope processes due to high speed of their motion combined with rather large size. It was found (Niyazov 2009; Niyazov and Nurtaev 2014) that many of them were associated with Hindu Kush earthquakes. Study of the effect of resonance caused by the long-duration low-frequency oscillations produced by such earthquakes and combined with the influence of precipitation

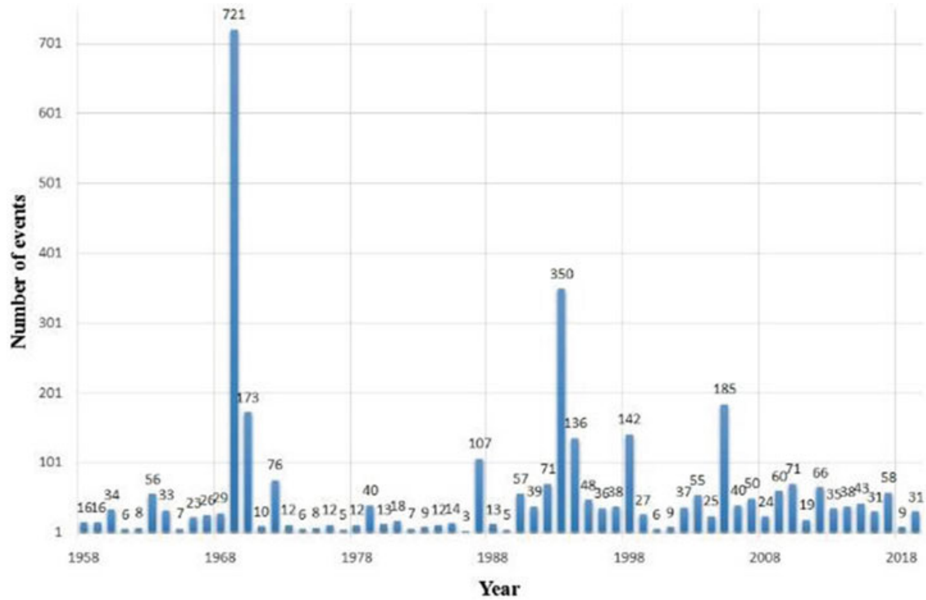

Fig. 2 Annual occurrence of landslides in Uzbekistan since 1958

on slopes stability was performed to fulfill the decisions of the Sendai Framework Program (Sassa 2017).

Self-excited Flow Slides in Loess

Loess deposits, widely developed in Uzbekistan, in the foothills in particular, are affected by numerous landslides. Many of them are the flow slides that demonstrate simultaneous crushing of soil over the entire landslide area. It results from the combination of several factors. It was found, in particular, that the frequency of seismic vibrations caused by the distant deep Hindu Kush earthquakes coincides with the natural frequencies on the slope causing resonance phenomena and the formation of landslides that we called "the self-excited".

The simultaneous destabilization of loess deposits over the entire flow slides source area differs from the formation mechanism of landslides of other types. Energy provided by seismic shaking leads to very fast propagation of the destruction of loess within the source area but has very limited effect on its further motion, in other words on its runout. Such landslides are characterized by the distinct sharp headscarp boundaries, where liquefaction occurs within the interbeds near the sliding surface, and sliding concentrates along a thin clayey layer. Soil crushing is caused by the compression-tension deformations mainly rather than by shearing, and develops simultaneously all over the affected slope from its top to base.

Several typical examples of such flow slides that occurred during last years, coinciding with deep Hindu Kush earthquakes are described hereafter.

The Achiyak Landslide

The Achiyak flow slide (41.6383° N, 69.7813° E) was formed on March 25, 2018, almost simultaneously with the M 5.1 Hindu Kush earthquake recorded on March 25, at 3 h 17 min (local time), with a focal depth of 297 km. Duration of oscillations was 90–95 s, dominant frequency 0.8–2.1 Hz. A landslide was formed in loess with a thickness of 15–20 m, lying on the water-encroached sandy-clayey rocks. The headscarp shape is rectangular, 80 m wide, 60 m long and 17–18 m deep. The estimated failure volume of 86.4 thousand m^3 (Fig. 3). The landslide mass broken in separate blocks moved into the riverbed, forming a blockage up to 100 m wide, 15–25 m long and 5–8 m high. The headscarp wall is almost vertical and is rather straight in plan view. It can be assumed that the formation of a landslide was associated first by tension with a successive sliding.

Fig. 3 The Achiyak landslide and location of seismometers (1–7)

The sliding surface zone of the landslide is gently dipping with an angle of 4–6˚. The seismometric measurements were carried out at 7 points located around the headscarp (see Fig. 3). Recorded resonance frequencies at measurement points 1, 3, 4, 6—were 1, 2; 2.2; 2.5 Hz, while at the lower marginal zones at points 5 and 7, they vary from 3.0 to 3.5 Hz. The horizontal to vertical ratios of the spectra (HVSR) vary from 2.6 to 3.4. The coefficient of seismic liquefaction of soils ranges from 3 to 9.6, which characterizes fairly dense rocks. It can be assumed that loess mass excitation most likely started at the upper and central part of the landslide where frequency of earthquake vibrations was close to natural vibration frequency of 2.2–2.5 Hz.

The Khandiza Flow Slide

The Khandiza flow slide (38.587° N, 67.5727° E) 1.5 million m^3 in volume was formed on April 6, 2015 (Fig. 4). It occurred in loess with a thickness of 12–15 m to 30 m, lying on the Cretaceous clays with interbeds of sandstones. It was preceded by the intensive (43 cm in one day) snow fall on February 24, 2015, and its fast melting with a rate of 2–8 cm per day during the last days of March that caused significant watering of subsurface soils. In addition, according to local residents, from April 2 to 5 there was watering the garden located on the landslide body. Landslide was triggered, likely, by the M 4.2 Hindu Kush earthquake that occurred on April 5, 2015 at 5:22 (local time) at a focal depth of 128 km.

In 23 days, the total horizontal movement of the landslide front was 960 m, while during first four days it moved for 570 m. After that the front displacement rate started decreasing. On the 12th day, when the front displacement was 954 m, the height of the tongue part began to grow from 10 to 25–30 m and the front width increased from 20–30 m to 40–75 m. The proximal part of the landslide displaced by 250 m in 23 days, and its displacement rate was relatively uniform—20 m/day on average. Here the stabilization process also began on April 12, when speed started decreasing up to 7 m/day and, later to 0.1 m/day. In the middle part of the landslide total horizontal displacement was 317 m. This is three times less than the movement of the frontal part. Moreover, in the first four days this part moved for 25 m only, i.e. the rate was the lowest, and the highest occurred from April 11 to 17 at a speed of 40–70 m/day. During this period different parts of the landslide moved uniformly. The stabilization process began on day 16, April 21, when speeds fell to 2–0.2 m/day. In the process of stabilization of the landslide, the most mobile was the middle zone, i.e. the flow slide moved in pulses.

Fig. 4 The Khandiza flow slide after its reactivation in March 2017

Next activation occurred in the spring of 2016 when, due to rainfall, surface displacements were observed in the tongue part of the landslide. Mudflows formed a furrow along the right side of the flow slide up to 800 m long, 5–6 m deep, and 8–10 m wide, from which about 20 thousand m^3 of landslide masses were eroded.

Two years later, on March 31, 2017, at 10 a.m. landslide reactivated again. It can be assumed that this activation (Fig. 5) was predispose by the formation of this erosion feature.

About 150 thousand m^3 of heavily watered loess up to 100 m wide and 5–10 m thick from the upper part of the slope, along with up to 250 thousand m^3 of loam located downslope that had been displaced in 2015, moved along a slope of 10–12° and created the flow slide up to ca. 1200 m long and from 30 to 100 m wide. Experts of the Surkhandarya monitoring station organized regular monitoring of its movement. It was found that the head and middle part of the landslide on the first day moves at a speed of 3 m/h, tongue 4–5 m/h, and the horizontal displacement was 70 m. As a result in the second day (April 1), the accumulation zone of the 2015 landslide was severely deformed by a series of arcuate cracks up to 30–40 m long. The bulging bars up to 2.0 m high divided with furrows up to 7.0 m deep and the activated landslide deposits moved into the old creek channel at a speed of 2.5–3.0 m/h. The flow width increased sharply from 1.5 to 60–100 m, the flow rate was 3.0–4.0 m/day and increased up to 50 to 80 m/day, being 60–80 m wide and 5–10 m high.

On the fourth day (April 3), the total displacement of the 80 m wide and 10 m thick flow slide reached 230 m at a speed of 3–4 m/h. The landslide reached the school building and began destroying it (see photo at Fig. 5).

In the next two days (April 4–5), the displacement of the landslide masses was divided into two directions: one went along the Kharkushsai channel in the form of a mud stream at a speed of 20–25 m/h; another in the form of a slide towards the school at a speed of 4.0 m/h. As a result, on the territory of the destroyed school, the thickness of landslide

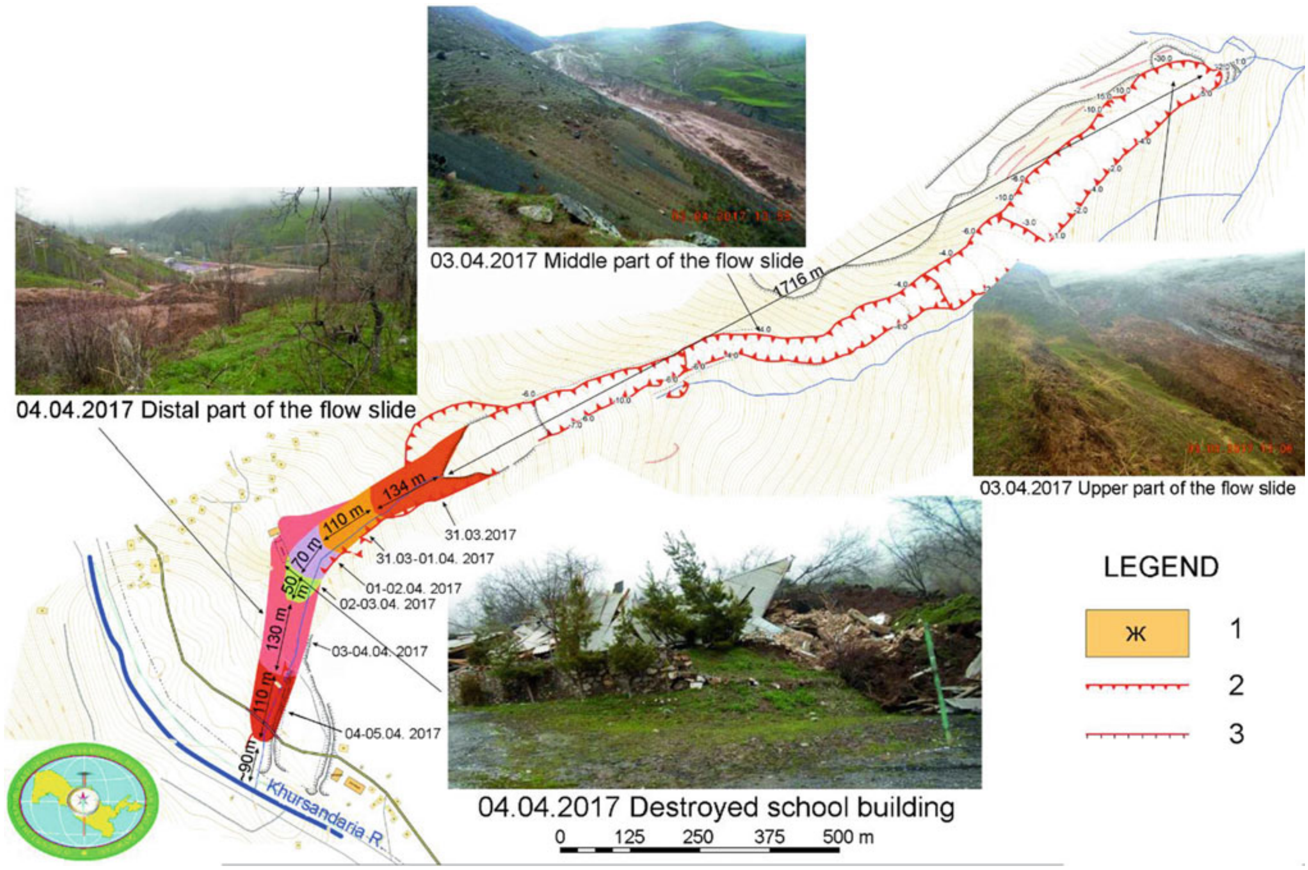

Fig. 5 Schematic map of the Khandiza flow slide activation in March–April 2017 compiled by the State Hazardous Geological Processes Monitoring Survey. Legend: 1—buildings, 2—main headscarp, 3—additional scarps and fissures. Different colors mark parts of the flow slide where it moved from March 31 till April 5.

masses increased up to 18–20 m, the width of the landslide reached 150 m, and the total amount of landslide displacement was 460 m. This displacement of the landslide provoked the movement of soil downstream.

On April 6, 80–100 thousand m^3 of debris moved further downstream the gulley at a speed of 5–6 m/h, reached the Khursandarya River and partially blocked its riverbed. The width of this partial blockage was 70 m, it was up to 3.0 m high and the volume of the dam was estimated as about 50.0 thousand m^3. During the following days the liquefied flow slide mass continued moving into the river and was gradually eroded by water flow.

The Otbokarsai Flow Slide

On April 23–28, 2019 a landslide of 1.5 million m^3 in volume originated on the upper part of the left-bank slope of the Otbokarsai River—the tributary of the Djinnidarya River (39.2048° N, 67.3735° E) (Fig. 6) and converted into highly mobile flow slide.

Fig. 6 The Otbokarsai flow slide source zone

Its source zone was composed of loess and of the underlying Cretaceous sandy-clayey red beds. The landslide formation took place in three nearby circus-like headscarps. The first—the central one—was located at the transition from the slope to the watershed surface, the second one occurred simultaneously to the right from the firs. In plan view the landslide had a conical shape with a very narrow (12–15 m) exit at the headscarp base trough which landslide had to pass moving downslope. The steep backwall was up to 300 m long and 35–40 m high.

The third, the largest circus-like headscarp, originated on the watershed surface. According to the local shepherd who attended the event, it occurred at 6–7 p.m. (local time), i.e. 11–12 h after the first slope failure. The 270–290 m long and up to 31 m high backwall crossed the watershed surface. The initial block slide was 300 m wide, and 120–140 m long and up to 20 m deep. The entire landslide mass rapidly converted into fragmented and liquefied state. As a result of the simultaneous movement, there was local blocking of this flow-like motion. On the left side there are traces of splashes of liquefied mass, 15–20 m high that left patches of debris 0.2–0.3 m thick. As a result, the flow slide passed for about 240 m and stopped in the upper zone, forming a blockage. The trigger for the start of the landslide was probably the Hindu Kush M 4.2 earthquake that occurred, according to the catalog, on April 23, 2019 at 6 h 31 min (local time) at a depth of 198 km, i.e. at the same time when landslide had started forming. And intense rainstorm on April 23 with cumulative precipitation 35.2 mm followed next day by even stronger (43.6 mm) rainstorm, provoked watering of the liquefied soil and the formation of a rapid flow slide.

The first time, on April 25, 2019 morning, this flow slide passed along the gulley and blocked the Otbokarsai Creek. The natural dam was 5–8 m high only and 30–40 m long. The discharge of this creek was up to 0.5–0.7 l/s. Water accumulated until April 26, when the blockage was breached producing the mud flow that passed along the Otbokarsai channel at a distance of 810 m, being 20–40 m wide. It reached the larger Djinnidarya River and partially blocked it.

The second time a mud flow occurred on April 27 when the flow 8.0–10.0 m thick passed along the creek. This mudflow also passed 810 m and blocked the Djinnidarya River again. This time the blockage was 270 m long, 80–110 m wide and from 8 to 15.0 m high. Volume of the blockage was 350 thousand m^3. The discharge of this river was 5–6 m^3/s. Within 3 h a dammed lake 200 m long, up to 110 m wide and up to 8–10 m deep was formed. After that its erosion started at the right bank river side.

The third mud flow originated on April 28 and blocked the Djinnidarya River channel again forming the dam 4–6 m higher than at the second time, so that the highway was blocked. The more than 200 m long dam was eroded in the zone of the old channel. The erosion channel was 7–10 m deep and 8–12 m wide.

Photo of the Otbokarsai Creek made on May 16, 2019 (Fig. 7) show that mud flows were 10–12 m thick, with a flow width of 35–40 m, a gradient of 6–8°, and that practically no debris accumulated in the channel.

Fig. 7 The Otbokarsai channel after the mud flow

Conclusions

Uzbekistan is a very landslide-prone country where more than 3500 landslides occurred during the last 60 years. The flow slides in loess are the most hazardous and unpredictable and pose especial threat. Analysis of the disasters associated with such events show that in many cases it very difficult to foresee their runout, location of the sites where the liquefied loess could be ejected from the channel on the opposite slope and height of such ejection. Timely prediction of such events is even more complicated due to their association with seismic shaking.

Such self-excited flow slides are triggered by low-frequency (0.5—3.5 Hz) prolonged (90–140 s.) vibrations produced by P-waves of very distant (400–700 km) deep (180–270 km) Hindukush earthquakes that cause simultaneous liquefaction of subsurface saturated sediments and tension in the surficial layers.

The characteristic feature of such flow slides is their recurrent simultaneous activation. Increase of the amount of the affected soil does not increase the velocity of motion, but enlarges the runout. Thickness of moving flow and its mechanical properties are often almost the same along the entire length. Loess flow slide are usually 1.5–3 m thick, while clayey flow slides can be 8–10 m thick.

Study of the eroded landslide dams produced by the flow slides show that their volume can comprise up to 30% of the entire flow slide volume if it crosses the dammed valley, and up to 80% if the flow slide moves along the valley. In both cases dams' height rarely exceeds 2.5–4.0 m.

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