

USOY NATURAL DAM: PROBLEM OF SECURITY (LAKE SAREZ, PAMIR MOUNTAINS, TADJIKISTAN)

A.R. ISCHUK

Institute of Earthquake Engineering and Seismology of the Academy of Sciences of the Republic of Tadjikistan

INTRODUCTION

Landslides and rockfalls can provoke river damming, valley impoundment, and as a result, floods and debris flows after dam's breach (SCHUSTER, 1993). Such phenomena are common in mountainous regions and often occurred in Tadjikistan in the past and recent times. The well-known Sarez, Yashilkul, Zorkul Lakes in Pamirs, the Iskanderkul Lake and the cascade of Shing Lakes in the Southern Tien Shan exist till now. There are 1300 lakes with total area of 705 km² in Tadjikistan. Most of them have the water surface less than 1 km² so that 97.5% of these lakes cover only 9% of the total impounded area. Practically all lakes in Tadjikistan have been created by landslides and rockfalls including those triggered by earthquakes, and by moraine deposit (glacial lakes).

Most of the lakes (73%) are situated in the Pamirs and Alai Mountains at 3500-5000 m a.s.l. altitude and, thus can be classified as alpine lakes. They accumulated 46.3 km³ of water, 20 km³ of that is fresh water. Furthermore, there are 9 man-made reservoirs with 664 km² of the total area of water surface, which accumulated 15344 km³ of water. These reservoirs have 7.63 km³ net storage volume that is 13% of the average annual flow of all rivers of the Aral Sea basin (NEGMATULLAEV *et alii*, 2003).

Two unique dams are located in Tadjikistan: the Usoy blockage – the highest (up to 670 m) natural dam in the World, and the Nurek Dam – the highest (300 m) man-made embankment dam in the World.

It is a rule that large man-made embankment dams are safer than natural landslide or rockslide dams. They have special design including spillways, special technology of erection and special monitoring system. Nevertheless, numerous large natural dams in the mountainous regions, most of which have been formed by slope failures triggered by strong earthquakes exist for hundreds and even thousands years. However the lifetime of the others is rather short and they pose a threat to the people living downstream. The actions for reduction of risk due to natural disaster like that of natural dam outbursts and floods, are very important for this reason.

The Lake Sarez is a good example of the outburst flood risk study and assessment. It was formed by strong (M 7.4) earthquake on February 18, 1911 when the huge landslide (about 2.2 km³ in vol-

ume) buried the Usoy village and dammed the Murgab River (Figure 1). Most of the inhabitants were killed (only 4 survived because they were not in the village at that time). The lake started forming upstream from the dam and in Summer-October, 1912 the larger Sarez village (6 km upstream from the dam) was inundated. For this reason the lake was named the Sarez Lake and the dam was named the Usoy blockage. The water didn't pass through the Usoy Dam until 1914 when in the autumn the filtration of water from the lake started and Murgab River appeared again.



Figure 1 - Satellite image of the Sarez Lake, Pamirs Mountains, Tadjikistan

GEOLOGICAL PATTERN OF THE SAREZ LAKE AREA

The Pamirs Mountains is a part of the Himalaya – Hindukush – Karakoram – Pamirs mountain belt formed by of Euro-Asian and Indo-Australian plates' collision and is one of the most active tectonics zone in the World (LUKK *et alii*, 1995). It comprises several regional sub-latitude thrust faults and the Sarez Lake area lies within the Rushan-Pshart thrust fault zone. Rocks within this fault zone are crushed and mylonitized, resulting in extensive fracturing of the rock mass and the formation of shear zones and cleavage. High degree of fracturing led to the practically permanent rockfalls and talus formation along the slopes on the right flank of the Murgab River Valley. The talus slopes have an angle of repose between 35 and 40° and form rock glaciers in the upper part of the slopes (above 4000 m a.s.l.).

Usoy landslide occurred on the southern slope of the Muzkol Ridge. The landslide scar is incised in the Perm-Triassic deposits (dolomite, limestone, gypsum, anhydrite) in its upper part, while its main portion – in the terrigenous-carbonate deposits (sandstone, schist, quartzite) of the Carboniferous Sarez Formation. These two units are divided by the Usoy Thrust dipping 60 to 80° towards SE. Besides this fault there is one more shear zone dipping 50° towards NW at the eastern part of the scar. Large-scale slope failure was caused by the collapse of the wedge delimited by these two fault planes. The bedding planes dip mainly 30 to 45° towards NNW, but with marked local variations due to the local folding and faulting.

The left bank of the Murgab River valley is formed by the same types of rocks, also belonging to the Carboniferous Sarez Formation, but their tectonic conditions are less complex than on the right side of the valley.

Thus, the location of the Usoy slope failure was determined, in general, by the combination of several tectonic factors (USOY LANDSLIDE, 2000):

- high degree of rock fracturing formed by the previous tectonic movements;
- the presence of major Usoy Thrust;
- the series of large shear zones that formed the conditions favorable for a typical wedge failure;
- the presence of an active wrench fault trending SW-NE just in the innermost corner of the wedge.

The main part of the landslide body consists of quartzite, sandstone and schist of the Sarez Formation and its northern part – of marble and shale with subordinate gypsum, anhydrite and dolomite of the Perm-Triassic age.

The internal composition of the Usoy Dam is not known. According to surface observations, huge and abrupt variations in its grain-size composition can be expected. Fragments size may range from sandy-silty material to blocks and boulders more than several cubic meters in volume. We can divide the dam body into three parts. Southern part of the dam is the highest one with a maximum height of about 250-270 above the lake level. Its surface is covered by blocks of various sizes from 2 to 20 m with no fines visible. Along the southern limit of the dam body there is a unit composed of pebbles of granite with typical fine loam moraine “matrix” that rest on the Carboniferous deposits of the left bank. We interpret them as the moraine deposits bulldozed in front of the rockslide. Similar deposits are also clearly visible at the upstream side of the dam body near the Shadau Lake. Central part of the dam body lies 100 m above the lake level on an average and has the sharp escarpment at its right side, where the surface is lower. The latter part is composed of strongly comminuted material without large blocks. Moreover, at some sites we can see the “natural slope surface” that indicate that a huge block moved intact. Northern part of the dam (Figure 2) is the lowest one with a minimum freeboard of approximately 38-45 m. This part is covered by large blocks of sandstone and shales from 2 to 20 m in size without fines on the surface. The part that abut to the right flank of

the Murgab River is covered by the secondary debris flows and mudflows composed of limestone, marble, gypsum debris and fines from moraine deposits that rest at the upper part of the scar and in the glacier valley above it.

From north to south three steps are clearly visible in the central



Figure 2 - Helicopter view on the proximal (northern) part of the Usoy Dam

and southern parts of the dam. The first (upstream) step looks like the ridge with very steep (60-70°) slope. The crushed and broken surface of the next step is clearly visible from this ridge. Along the downstream face of the dam (close to the western scar’s wall) a large cone of fine debris flow material has been deposited since the dam formation. This debris flow deposit rests partly on the blocky dam material and this depositional mass is terminated by a local canyon on the downstream face of the dam, which has developed due to erosion caused by the seepage flow.

Analysis of the Usoy Landslide body and scarp allow suggesting the following mechanism of the slope failure. After earthquake the huge wedge of rocks slumped down very fast like a single block. The speed of movement was very high and when this block hit the valley bottom it started overturning to the south and separating lengthwise into three big parts, which, in turn, destroyed into smaller blocks. Several smaller rock falls from the western wall of the scarp occurred

during and after earthquake as well. Later on several small landslides were formed at the northern part of the dam body where rockslide debris is overlaid by the debris flow deposits.

THE SAREZ LAKE HYDROLOGY AND PERMEABILITY OF THE DAM'S BODY

The main parameters of the dam are as follows: maximum height of the dam – 620 m; minimal recorded height of the lowest part of the dam above the lake level – 38 m; maximal height above the lake level – 288.8 m; dam volume – 2.2 km³; dam length – 5 km; dam average width – 3.2 km; dam area – 10.8 km²; difference between lake level and canyon springs point – 148.2 m; number of the springs in the canyon – 57;

The main parameters of the Sarez Lake: length – 55.8 km; average altitude of the lake level – 3263 m; maximum width of the lake – 3.3 km; maximum depth of the lake – 500 m; average water inflow – 47.1 m³/s (1487 million m³/yr); average water outflow – 47.7 m³/s (1505 million m³/yr); maximum seasonal oscillation of the lake level – 12 m; maximum volume of water in the lake – 16074 km³. I must note that accuracy of these data is questionable. Since the lake level gradually increases it could be assumed that inflow must exceed outflow. Nevertheless the above values have been recorded.

All of the 57 springs on the downstream slope of the dam are located in the canyon at nearly the same topographic level – approximately 3100 m.a.s.l. or 140-150 m below present lake level. It is also known that the springs appeared as the water level reached about 3100 m.a.s.l., so the dam below this level should be impervious. The discharge from all springs is 35-75 m³/s (season variation) and depends on the lake level. The annual lake level variation is ±6 m.

The lake level increased very rapidly during the 1911-1914 and when it reached the 3050 m, the filtration started in spring 1914 with about 2 m³/s discharge. In 1925 discharge reached 78 m³/s in summer, and was decreasing to 50 m³/s up to 1940. After that during long time the annual discharge was more stable, though varying from 32 m³/s (in winter) to 73 m³/s (in summer). The highest level of 3270 m was recorded in 1994 when maximum depth reached 520 m and the lowest part of the dam was only 38 m higher. The perennial observations indicate very slow increase of the seepage outflow (Figure 3) and attenuating growth of the average, maximal and minimal lake levels (Figure 4).

DAM STABILITY ASSESSMENT

There are two conflicting points of view on the Lake Sarez problem concerning its stability. The first one is that the Usoy Dam is an unstable structure and overtopping can occur after some time causing giant outburst flood that will demolish the Bartang and Pyandj River valleys. The opposite point is that the Usoy Dam is a stable natural structure and the Sarez Lake will exist long time like other similar lakes such as the Yashikul Lake in Pamirs, Iskanderkul Lake in Central Tadjikistan and many others (ISCHUK, 2000).

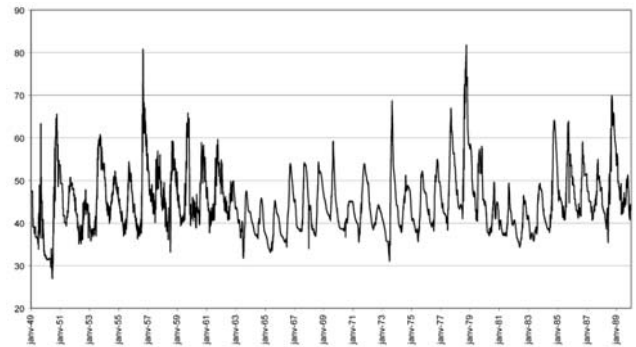


Figure 3 - Evolution of seepage outflow from 1949 to 1989 (m³/s) (after BIEDERMANN & ATTEWILL, 2002)

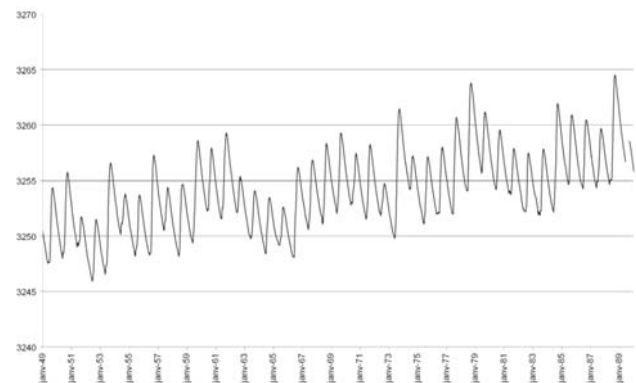


Figure 4 - Evolution of the Sarez Lake level from 1949 to 1989 (after BIEDERMANN & ATTEWILL, 2002)

I hold the second opinion. The stability of the dam with regard to very compact structure and huge dimensions of the dam body (Figure 5) is admitted to be guaranteed with a high safety factor. The morphology of the dam surface however shows that some secondary movements have taken place. As a matter of fact a settlement of up to 75 m is mentioned in various reports. The origin of such deformations is not known, and can be due to compaction (earthquake induced or not). But the latest investigation showed that contemporary surface subsidence does not exceed 5-10 mm per year (VINNICHENKO, 2000; STUCKY, 2001).

The water flow from the lake to the downstream springs is assumed to be very rapid – 2-5 m/s, though measurements performed in the past are not completely consistent. The “intake zone” about 1000 m long was identified on the upstream slope of the dam. Seepage water is going out towards the canyon eroded at the downstream slope of the dam. The head of the canyon is about 1500 m from the lake, at 3110 m. The average hydraulic gradient through the dam is 10%.

Taking into account the average hydraulic gradient of 10%, and a Darcy coefficient K corresponding to a flow through large-size

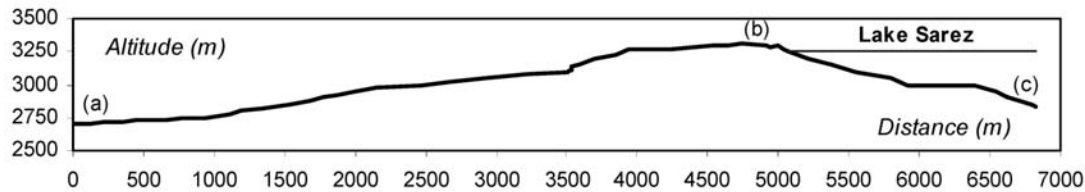


Figure 5 - The Ussoy Dam cross-section (after BIEDERMANN & ATTEWILL, 2002)

gravel without fines ($K = 10^2$ cm/s), it was found that the maximum velocity of water through the dam should not exceed some decimeters per second, i.e. 15 to 60 times less than the measured values (BIEDERMANN & ATTEWILL, 2002).

“These observations lead to the conclusion that the structure of the seepage zone consists of a vast inter-block system through which run preferential hydraulic ways. The high-recorded seepage velocities and the springs are related to the preferential hydraulic ways. Presently, the exact rate of water flowing through the preferential hydraulic ways and through the inter-block system is not known. However, we know that none of these two phenomenon is negligible” (BIEDERMANN & ATTEWILL, 2002).

The canyon eroded by the filtrating water will progress in its actual direction, along the contact between the collapsed carboniferous material and the debris flow and mudflow sediments (see figure 2). In this case the head of the canyon would progressively approach the zone of the lowest part of the dam, but significantly slower than it would have been along a direction transverse to the dam body.

REFERENCES

- BIEDERMANN P. & LAURENCE A. (2002) - *Evolution of Seepage Through Landslide Dams. The Case of Ussoy Dam in Tajikistan*.
- ISCHUK A.R. (2000) - *Critical analysis of the works executed on Lake Sarez – Geological aspects of the problem*. In Lake Sarez Risk Mitigation Project, Dushanbe, 2000.
- ISCHUK A.R. (2001) - *Lake Sarez – current knowledge about the problem*. *Izvestia Academy of Sciences of the Republic of Tajikistan*. Department of Physics, Mathematics, Chemical and Geological Sciences. No 1.170-1
- LUK A.A., YNGA S.L. & SHEVCHENKO V.I. (1995) - *Earthquake focal mechanisms, deformation state, and seismotectonics of the-Tien Shan region, Central Asia*. *J. Geophys. Res., Solid Earth*, **100** (B10): 20321-20343.
- NEGMATOULLAEV S.Kh., VLADUT T.J. & ISCHUK A.R. (2003) - *Big Reservoirs in the Seismic Dangerous regions in Tajikistan and Safety of Dams*. Second edition. TIEES, Dushanbe. 60 pp.
- SCHUSTER R. L. (1993) - *Landslide dams – a worldwide phenomenon*. In Proc. Annual Symposium, The Japan Landslide Society, Kansai Branch, Osaka, 27 April, 1-23.
- STUCKY CONSULTING ENGINEERS (2001) - *Design report – Monitoring and Early Warning Systems / Studies on Long Term Solutions: Lake Sarez Risk Mitigation Project*, Renens.
- Ussoy Landslide Dam and Lake Sarez. An assessment of Hazard and Risk in the Pamir Mountains, Tajikistan. 2000*. UN Publication. Sales No. E.00.III.M.1. D. Alford, and Robert Schuster (Eds.)
- VINNICHENKO S.M. (2000) - *Geodetic and geological studies executed in the Lake Sarez Region – review, analysis, recommendations*. In Lake Sarez Risk Mitigation Project, Dushanbe, 2000.

Though the detailed internal structure of the Ussoy Dam is unknown, all data available indicate that there is no danger of a general dam failure due to the water pressure against the upstream face. Moreover, “even under an extremely heavy earthquake with horizontal acceleration of 0.5 g, the estimate of the safety factor still result in a safe value” (*Ussoy Landslide Dam ...*, 2000).

CONCLUSION

The Ussoy Dam is stable and can not be destroyed by the internal erosion or overtopping owing to its composition, structure and huge dimensions (ISCHUK, 2001).

The main unfavourable scenario is the overtopping of the Ussoy Dam due to the lake level increase caused by the change in the seepage conditions after strong earthquakes, increasing inflow to the lake, etc.. But in this case we can not expect the catastrophic consequences, because the body consists of hard rocks and can not be destroyed too fast.