DOI: 10.4408/IJEGE.2006-01.S-29

NATURAL AND ARTIFICIAL ROCKSLIDE DAMS IN MOUNTAIN GEOSYSTEMS OF KAZAKHSTAN OROGENIC BELT

V.P. Bochkarev

The K.I. Satpaev Institute of Geological Sciences, Almaty, Kazakhstan

INTRODUCTION

The Orogenic belt of the South-Eastern Kazakhstan is formed by the northern arches of the Tien-Shan, Dzhungaria, Saur-Tarbagatai, Altai divided by the intermountain areas. It is characterized by the intensive neotectonic movements and high seismic activity (6-9 degree of the MSK-64 scale and even more). They formed the modern relief and cause intensive endogenic and exogenic geodynamic processes. Endogenic phenomena, associated with seismic events, follow strong earthquakes and are expressed as linear and three-dimensional dislocations. Gravitational-seismotectonic deformations combine elements of linear tectonic fractures and gravitational displacements of large blocks. Such dislocations are rockslide dams, which have volumes of displaced rock masses of several hundreds million cubic meters, as well as blockages of the river valleys caused by thrust faulting. Among such lakes are Great Almaty Lake (GAL), Issyk, Kolsai, etc. (Tien-Shan), Zhasylkol (Dzhungaria) lakes.

THE GREAT ALMATY LAKE DAM

Over 100 years, specialists in geology, seismology, tectonics, geography, geomorphology, glaciology were engaged in researches of the natural dam of GAL. I.V. Mushketov *et alii* (1890), who surveyed the effects of the catastrophic earthquakes in the Northern Tien Shan interpreted this rockslide dam as "a huge finite moraine" (Bogdanovich *et alii*, 1914, p. 27) or "a subbottom moraine" (Vinokurov, 1908, p. 7). Geological surveys, specialized explorations and our researches, carried out for the last few decades, showed that the natural dam of GAL is a seismically triggered rockslide. Most likely its formation was associated with the catastrophic earthquakes (M > 8), which epicentral zones were located at the system of Gorelnik faults of the Zaili Alatau seismogenerating zone.

Numerous paleoseismodislocations coincide with regional faults striking north-east and auxiliary faults. Dating of these events is still controversial. Formation of the GAL dam rockslide was not a single-stage process. Different researchers consider the rockslide age as 2-10 thousand years or even older than Holocene. According to our estimations of the regional paleoseismic structures, the most probable age of the dam formation is the Early Holocene (about 10 thousands years). Later on considerable amounts of rock masses fell down from both slopes of the valley on the main rockslide. Scars of these rockslides are traced from a watershed of the B. Almatinka and Shukur Rivers, on the slope of Mramornyi creek valley, on the east slope of the Bolshealmatinskiy Peak Ridge. Fragments of the blockages similar to that of the GAL dam, are found at the elevations about 2300 m a.s.l. in the Ajusai and Mramornyi creeks valleys, on the right slope of the B.Almatinka River 1.5 km upstream from GAL at the area more than 0.2 km^2. The Dzhusaly-Kezenskiy oblique-reverse fault is considered as the main active fault in the GAL basin.

The scenario of morphostructure formation of the GAL basin and rockslide seems to be as follows:

Early Holocene large-scale tectonic event was accompanied by graben-like subsidence along the axis of the modern B. Almatinka River valley just upstream from the modern dam that that stretches as far as the Kumbelsu River mouth.

The above subsidence was accompanied by the simultaneous uplift of the Bolshealmatinskiy Peak block, while the block that formed Mramornyi-Ajusai watershed was characterized by lower displacement values. The northern block of this ridge "lagged behind", or remained on the former place.

Rock slope failures at the northern and western slopes of the Mramornyi creek upper reaches formed the western and central blockages at the B. Almatinka River valley.

Fresh block failures at the surface of the blockage result from the subsequent seismic vibrations that affect the collapsed material.

The eastern part of the GAL dam was formed by similar seismo-gravitational slope failures of the valley's right slope section that affected the slope up to its watershed with the Shukur River valley.

In the uppermost part of the steep (40º) left slope of the Mramornyi creek large block-slides of bedrock 100-200 m high with average length of every step about 500-700 m are distinctly traced along the axis of the Ajusai-Mramornyi watershed.

The height of the scar reaches 600 m. Its surface is covered by the angular granite blocks up to 3-5 m in diameter. It is typical that sides of blocks with the rock varnish are oriented chaotically. There are surfaces with varnish and lichens cover turned to the north and even downwards. All this is indicative of rather young age of the crushing of blocks on the dam crest. At a distance of 0.5 km to the west from the GAL dam, in the middle part of slope on the block plane, covered with rock varnish petroglyphs, depicting a goat and a deer can be seen. This side is abruptly inclined to the horizon and obviously displaced. All this suggests that the varnish and rock drawings are older than the rockslide. We tried to restore a dynamics of rockslide debris motion by construction of the large blocks displacement vectors and their stacking order in the direction of movement. It was found that in all cases vectors of heaping were in conformity with the main gradient of the underlying relief surface.

The right-bank part of the rockslide dam from the Shukur River watershed side consists of two generations. The first one (to the south from the lake) goes down the valley up to 2550-m level. The rockslide extends along the right bank of the river almost for 2 km and forms a steep slope (>40°) of the river channel. This seismogravitational structure was formed as a rockslide associated with normal faulting and, according to profile shooting, includes large collapsed blocks (up to thousands cubic meters in volume) and disintegrated rock masses. The seismic boundary, dividing poorly and strongly consolidated debris, is at the depths of 5-20 m. The upper part composed of blocks and rubbly debris is characterised by the velocity of the elastic waves of 0.5-0.6 km/s; lower, consolidated part of the section, has velocities of 0.8-1.5 km/s, while velocities at the valleys' rock basement range from 2.5 to 3.3 km/s.

The second large collapse from the western slope of the Shukur ridge rests at the east slope of the GAL depression and stretches as an abrupt spur in the northern direction almost for 2 km. Its crest height decreases from 2650 m.a.s.l. in the south up to 2400 m.a.s.l. in the north. The frontal scarp of the rockfall and its proximal scarp are practically rectilinear, 50-70 m high and are inclined 10-40º. It is covered by blocks up to 15 m long, with visible hollowness in its body up to 10 m and more. Sometimes a person can walk between these blocks. The entire material practically is not rounded, only fresh chips are observed on sharp sides of blocks.

The total area of the GAL rockslide dam is approximately 4.5 km^2. It is 2.5 km long, 1.5-2.5 km wide and its total volume is estimated as about $250\text{-}350 \times 10^6$ m^3.

Permafrost was found at the elevation of about 2500 m in the coarse facies of the dams' body at a depth up to 50 m, while the depth of seasonal freezing does not exceed 4 m. Rock soils here are icy, while debris contains more than 10% of ice. According to A.P. Gorbunov, it is the relic permafrost of "The Minor Glacial Epoch" that lasted during XIII-XVI centuries A.D. Similar phenomena were found in the Issyk River valley at an elevation of 1900 m. The permafrost age at this side was determined as 2700 years.

In order to determine the position of rockslide basement and to study heterogeneity of its body a complex of geophysical works including seismic prospecting and electrical sounding was carried out. It was found that delta of the B. Almatinka River has three-layer structure. Poorly consolidated clumpy debris with sandy loam filler 5-20-m thick lies on top. Below there are 20 m thick more consolidated similar deposits underlaid by the boulders and gravel with sandy-sandy loam filler. Thickness of these Holocene alluvial deposits is up to 80 m. Bedrock valleys' basement is asymmetric, with its most deeply incised part near the right bank. Several faults are traced within valley basement with 20-40 m amplitudes of vertical displacement. Distinct faults, framing the graben block, are traced along the valley slopes. There are also systems of the transverse faults, which form steps in the longitudinal profile of the valley basement. Maximal thickness of the rockslide body (130-150 m) was registered at a distance of 1-1.5 km north from the Great Almaaty Lake.

Filtration discharges of underground waters through the dams' body are well correlated with the lakes' level. When the water surface is 2500 m, discharge is constant and close to 0.4 m^3/s. When it increases up to 2506 m, discharge increases as well up to 2.5 m^3/s. Geological-geophysical data allow us to draw the conclusion that active filtration stream exists in the upper part of rockslides at a depth of the first tens of meters. Heterogeneity of structure of ground stream appears as zones of descending and ascending water-currents. Taking into account high hollowness of the rockslide body and prevalence of block material (up to 70%) in its composition, it is believed that its whole thickness is water-saturated. Water of the lake and springs on the low slope of the natural dam are ultrafresh (0,2-0,4 g/l), hydro-carbonaceous-calcium.

Debris flow sediments gradually fill the lake and by 1952 its depth was 33 m, water volume – 8.1 x 10^6 m^3, and the natural spillway level – 2499 m. Water of GAL is used for water supply of the Almaty City and for the cascade of high-head hydroelectric power stations. For optimisation of water-energy indexes of the cascade and provision of high degree of safety in case a debris flow with volume up to 4.5 x 10^6 m^3 that can enter the lake, the embankment dams 10 m high were built on the rockslide crest in 1952 and 1982. Volume of water in the lake increased up to 13 x 10^6 m^3 at a headwater level of 2507 m. The lake and its basin are situated in a zone with possible intensity of earthquake up to 10 points of the MSK-64 (MM) scale. Catastrophic earthquakes in 1887, 1889, 1911 with magnitudes 7.3-8.4 did not cause marked deformations of the natural rockslide, but moreover, made it more consolidated and stable.

THE ARTIFICIAL MEDEO DAM

Construction of the Medeo artificial rock fill (blast-fill) dam was completed in 1976 in the Malaya Almatinka River valley, south from the Almaty city. It is the main structure of the complex protecting the Almaty agglomeration from debris flows. The valley of the Malaya Almatinka River is one of the most debris flow-prone. Disastrous debris flows with volumes up to 6 million cubic meters occurred in 1921 and 1973. Upstream from the Medeo dam there are numerous sources of debris flows within the glacial-moraine zone. The Medeo dam with the storage capacity of more than 12.6 x 10^6 m^3 cuts off up to 90% of debris flow sources. High probability of disastrous debris flow in this river valley stipulated completion fast construction of the storage dam. Therefore for the construction of the dam 110 m high and debris flow storage with a capacity of 6.2 million cubic meters, an alternative technology of powerful directed blasts was accepted.

The first right-bank blast of about 5.3 thousand tons of explosives performed at October 21, 1966 formed a blockage 62 m high 1.7 million cubic meters in volume. Seismic effect near the epicentre of explosion corresponded to 7 points of the MSK-64 scale. The blockage was formed by large blocks and rock debris with debris-sandy filler. Its density was 2.2-2.4 g/m^3 and the filtration coefficient – 13-38 m/day. The left-bank explosion of about 4 thousand tons of explosives performed on April 14, 1967 increased the height of the barrier up to 72 m. By the beginning of a mudflow dangerous period (July, 1967) the dam's height was increased up to 97 m. By 1972 the whole profile of the dam was completed.

On July 15, 1973 a break of morain lakes in the Tujuksu area generated a catastrophic debris flow with more than 10000 m^3/s discharge. The storage reservoir was filled with muddy-stone mass for 75% of its volume (5.5 x 10^6 m^3). Only emergency measures, undertaken by the whole country, made it possible to prevent the dam's break and to empty the overflowed reservoir. In 1973-76 the dam was reconstructed. 2.5 x 10^6 m^3 of rock mass from the left-bank rocky quarry and 1.0 x 10^6 m^3 of debris flow deposits from the reservoir were dumped into the dam's body. The dam was built up, its height was raised up to 150 m, and storage capacity was increased up to 12.6 x 10^6 m^3. Average density of the dam's body material is 2.2 t/m^3; the internal friction angle 37º; seismic waves can propagate in the dam's body at a velocity of 500 m/s; gradient of the upper slope is 1:1.6. The designed seismic stability of the dam is 9-10 degree of the MSK-64 scale. If such event will occur the predicted vertical displacement of the dams' crest, can reach 1.8 m. The dam is equipped with instrumentation, has the duplicated systems of spillways, both operational (30 m^3/s) and an additional one used in case of emergency and allowing to repair the main spillway. After its completion the Medeo dam underwent several earthquakes of 5-MSK intensity without any deformations.

CONCLUSIONS

Due to of high seismicity of the territory, large scales of the exogenic geodynamic processes (mudflows, landslides, collapses, snow-stone avalanches, etc.) manifestations and their activity, studying, mapping and monitoring of the blockages in the Orogenic belt of Kazakhstan have not only and not so much the scientific importance, but are extremely important from the practical point of view. Since mountain valleys and alluvial fans are densely populated and economically developed and it will increase in future the enormous scales and catastrophic consequences of such geodynamic processes as the Almaty debris flows of 1921, 1973, 1978, the Issyk debris flow of 1963, the recent (2004) landslide in the Talgar region, require development of the State program of their studying and monitoring.

The predicted processes of degradation of mountain glaciation (actually they have already started), activation of seismicity in the mountain geosystems of Kazakhstan's orogen also require realisation of such works as soon as possible.

REFERENCES

Bogdanovich K.I., Kark I.M., Korolkov B.Y. & Mushketov D.I. (1914) - *Earthquake in the Northern Chains of Tien-Shan on December 22, 1910 (January 4, 1911).* Proc. of Geological Committee, new series, issue 89, St. Petersburg. 252 p. (in Russian, extended abstract in French).

Bochkarev V.P. (2004) - *Dangerous Geodynamic Processes of Kazakhstan Orogenic Belt.* Geoecology, **1**: 41-45 (in Russian).

Bochkarev V.P., & Medeuov A. (1990) - *Slope Processes in Mountain Regions of South-East Kazakhstan.* Engineering Geology, **6**: 50-58 (in Russian).

Bochkarev V.P., Vardugin V.N. & Zhdanovich A.R. (1997) - *Estimation and Forecast of Mudflow Danger in Conditions of High Seismisity.* Geology of Kazakhstan, **1**: 25-34 (in Russian).

Mushketov I.V. (1890) - *Vernyi Earthquake on May 29 (June 9) 1887.* Proc. of Geological Committee. St-Petersburg, **10** (1): 154 pp. (in Russian).

Vinokurov A. (1908) - *Almaty Mountain Lake in Zaili Alatau.* Zemlevedenie, book III (in Russian).