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"REMOTE" LANDSLIDE-RELATED HAZARDS AND THEIR CONSIDERATION FOR DAMS DESIGN

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ABSTRACT

The 1963 Vajont disaster highlighted the importance of slopes stability analysis not only directly at the dam sites but also in the reservoir areas to ensure hydraulic projects safety. However, catastrophic collapse of huge rock/soil mass into reservoir does not exhaust negative effects of landslides that must be taken into consideration in the course of dams design. Severe consequences might result from river channel landslide damming both downstream from the dam site and far upstream from the reservoir. Their potential effects are exemplified by several case studies from the Central Asia region. Measures aimed to mitigate negative effects of such extreme events are discussed.

Key words: *rockslide dam, outburst flood, debris flow*

INTRODUCTION

The 1963 Vajont disaster highlighted the importance of identification of potentially unstable slopes identification not only directly at the dam sites but also in the reservoir areas to ensure hydraulic projects safety (Muller, 1964; Semenza, 2010; Paronuzzi & Bolla, 2012). Neither favourable geological conditions of the Vajont dam foundation nor excellent structural design of the dam that sustained the event much beyond the design basis had prevented the catastrophe caused by water splashed out from the reservoir by giant and extremely rapid rockslide.

However, catastrophic collapse of huge rock/soil mass into reservoir does not exhaust negative effects of landslides that must be taken into consideration in the course of dams design. Severe consequences might result from river channel blockage both downstream from the dam site and upstream from the reservoir. The former case will be described hereafter while the latter one can be exemplified by the 1970 Huascaran rock-ice avalanche. It blocked the Rio Santa River and converted into powerful debris flow that travelled 180 km along the stream destroying the Cañon del Pato storage dam more than 45 km downstream from the rock avalanche site (Plafker & Eriksen, 1978; Evans *et alii*, 2009).

These scenarios have been analysed within the frames of geological and hydrological investigations carried out for largest hydraulic schemes implemented in the Central Asia region - the Rogun dam on the Vakhsh River in Tajikistan and the Kambarata-1 & 2 dams on the Naryn River in Kyrgyzstan, which position is shown on Fig. 1. Some measures aimed to prevent or mitigate negative effects of "remote" hazards provided by extreme landslide-related events are discussed.

ROGUN DAM PROJECT, TAJIKISTAN

1993 BLOCKAGE OF THE VAKSH RIVER DOWNSTREAM FROM THE ROGUN DAM SITE

The 335 m high Rogun dam on the Vakhsh River in Tajikistan that should be the world highest earth-fill structure have been under construction since late 80s of the twentieth century. On May 8, 1993, powerful debris flow that originated in the Obi-Shur Creek that falls into Vakhsh River just downstream from the dam site (Fig. 2) had blocked the Vakhsh River channel. It brought diversion tunnels out of operation, caused inundation of the underground power house and breach of the cofferdam that resulted in years-long suspension of construction works.

The 57,4 km^2 Obi-Shur catchment (see Fig. 2) produces regular debris flows. Maximal measured discharge recorded before construction had started, in May 19-20, 1983, was 1150 m^3/sec. Rough estimates based on the height of debris flow traces on the walls of the Obi-Shur gorge (Fig. 3) gives even higher value of about 1 500-1 700 m^3/sec for an undated earlier debris flow. Density of debris flow deposits can reach 2.3-2.4 tons/m^3.According to observations temporary damming of Vakhsh River stream occurs every ten years on an average being caused by debris flows which volume can exceed 2.5 million m^3.

At present, after construction recommencement, special measures are undertaken to prevent similar phenomena. They include construction of the cellular concrete dam at the lower reach of the Obi-Shur Creek aimed to intercept the coarsest fraction of debris, that forms the skeleton of blockage and allowing water and fines that can be easily removed by the river to pass through the holes in the dam. On June 22, 2012, before completion of this protection dam, it stopped debris flow that lasted for about 7 minutes only, but with estimated peak discharge of ca 1 300-1 400 m^3/sec. 290-350 m^3/sec of it passed through the dam and was carried out by Vakhsh river and about 280 000 m^3 of debris was accumulated upstream from the dam (Fig. 4).

POSSIBILITY OF UPSTREAM RIVER DAMMING

Analysis of the possibility of river's damming by rockslides and surging glaciers in the upper reaches of the Vakhsh River basin, which breach can result in powerful outburst flood, was also performed for the Rogun dam project. The purpose of this study was to estimate excessive inflow into reservoir that should be considered, along with extreme 'hydro-meteorological' flood (PMF), to ensure dams' safety.

The entire catchment area of Vakhsh River upstream the Rogun dam site (Fig. 5) was checked using the remote sensing data available (Landsat ETM7 with 15 m and KFA-1000 with 5-10 m spatial resolution) to identify sites where large-scale river-damming resulting in lake formation can be anticipated.

Several sites where main stream could be blocked by surging glaciers were identified (see Fig. 5) based on the history of glacier rapid advances in the past (Osipova *et alii*, 1998). Though at present such phenomena are hardly possible due to intensive glaciers retreat in the Varhsh River basin (Kotlyakov, 2006), its potential hazard must be analysed with due regard to centuries-long life time of large hydraulic project such as the Rogun HPP. Maximal volume of lakes considered as the worst scenario in case of such surges was estimated as *ca* 170 Mm^3.

Despite rugged relief typical of almost entire study area and its high overall landslide susceptibility

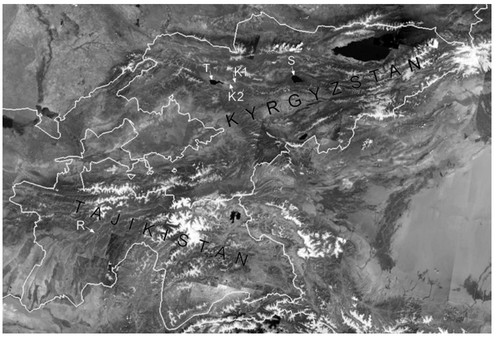

Fig. 1 - Position of the Rogun (R) and Kambarata (K1 & K2) dam sites in Tajikistan and Kyrgyzstan. T - the Toktogul reservoir; S - the Sonkul lake

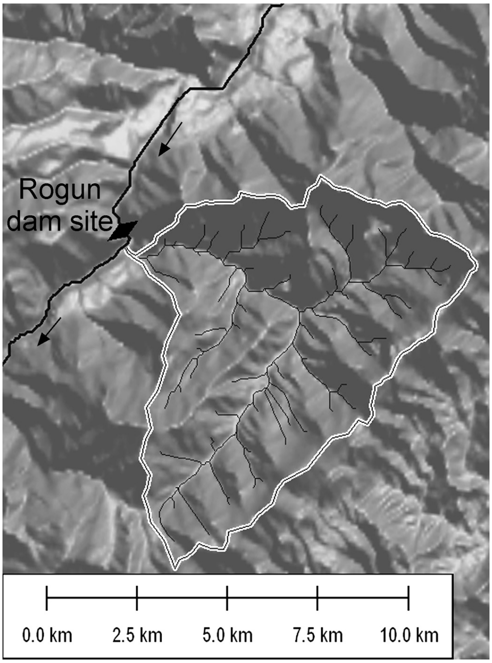

Fig. 2 - Obi-Shur Creek catchment area on 3" SRTM DEM

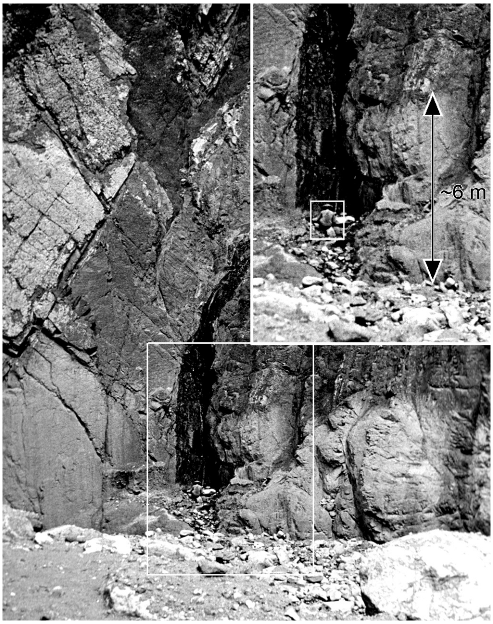

Fig. 3 - Mud pasted by debris flow at the wall of the Obi-Shur gorge. Person sitting in the cavity (see the inset) is about 1.2 m high, thus debris flow thickness (double-head arrow) was about 6 m. Photograph was made in 1978

only few sites where large landslides could originate casing blockage of main streams and formation of voluminous dammed lakes were identified.

The largest anticipated blockage could occur in the middle reaches of the Muksu River valley in Northern Pamirs (see Fig. 5). Here, at 39º7’ N, 71º45’ E, several large rockslides had occurred in the past on the 1.0-1.5 km high steep slopes causing river damming (Besstrashnov *et alii*, 2013). None of these dams survived. Such clustering typical of large-scale bedrock landslides in many parts of Central Asian mountains (Strom & Abdrakhmatov, 2004) can be considered as indication of increased probability of future failures within such node.

Assuming that rock slope failure in the relatively narrow valley could produce a dam with effective height of about 100 m, the dammed lake could store *ca* 200 Mm^3 of water - slightly more than those dammed by surging glaciers. Further calculations of the outburst flood parameters were performed based on worst scenario of complete failure of such rockslide dam caused by combined effect of both overtopping and piping, which seems to be quite conservative. Due to large distance from the site to the

Fig. 4 - June 22, 2012 debris flow in the Obi-Shur Creek stored by the protection dam. Photo courtesy V.S. Panteleev

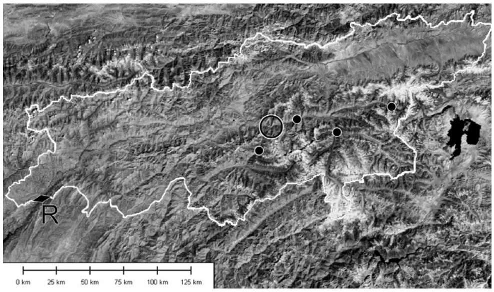

Fig. 5 - Vakhsh River catchment area for the Rogun dam site (R). Site of the Muksu River potential rockslide damming is marked by open circle; black dots mark sites where river damming by surging glaciers could be anticipated

Rogun reservoir (~160 km) even in worst case with peak discharge estimate immediately downstream from the breached dam of 134 000 m^3/s it would decrease at the tail part of the Rogun reservoir up to 5 700 m^3/s. Daily mean discharge at this section could reach 2 400 m^3/s and total amount of the "additional" inflow - 200 million m^3. Considering size of reservoir at normal operating level from 1240 to 1290 m such amount could increase water level up to 1.3-1.5 m only. Thus, the excessive increase of the maximal flood level caused by outburst flood would be close to its assessment accuracy, considering back-wash and normative dams’ freeboard. Though such excessive reservoir level would not provide significant risk, possible measures aimed to its mitigation are discussed in the conclusive section.

KAMBARATA-1 & 2 DAMS PROJECT, KYRGYZSTAN

The Kambarata hydraulic scheme on the Naryn River in Kyrgyzstan includes the 60-m high rockfilled Kambarata-2 dam constructed in 2009 immediately upstream from the Toktogul overyear storage reservoir and the 270-m high Kambarata-1 dam about 10 km upstream (Fig. 6), which construction is planned in the near future. The Kambarata-2 dam was partially built by powerful explosion and partially filled by rock mass (TORGOEV *et alii*, 2013).

The Naryn River valley have numerous evidence of past slope instabilities that had caused river damming, inundation and powerful outburst floods (STROM, 2012a). Several sites where similar phenomena could occur in future resulting in complex negative effects on these hydraulic power plants have been identified as well, both at the river valley section between dam sites and upstream from the upper reservoir.

POSSIBILITY OF STREAM BLOCKING AND KAMBARATA-1 POWERHOUSE INUNDATION

Several sites of the potential river-damming events that could result in inundation of the Kambarata-1 powerhouse have been found between the Dam 1 and Dam 2 sites (Fig. 6). Large-scale bedrock landslides caved from the slopes marked by 'A' and 'B' in the past, which is proved by the presence of rock avalanche deposits. At both sites rock avalanche deposits rest at the opposite banks of the Naryn River indicating that the stream had been blocked. At site 'A' blockage occurred twice - in Late Plestocene and in Holocene by rock avalanches up to 10-15 Mm^3 each (Fig. 7), though, most likely, for a short time, since no lake sediments were found upstream. Nevertheless, if similar slope failure will occur here in future, that can be assumed based on the evidence of present-day slope instability (Fig. 8) even temporary blockage several dozens meters high could inundate the Kambarata-1 powerhouse about 5.5 km upstream. Besides, an inevitable breach of such dam could severely affect the downstream Kambarata-2 dam, which freeboard is not large enough to accommodate such outburst flood.

Special technical measures aimed to prevent such effects include excavation of the bypass channel across river meander shown as triple black line on Fig. 6. If local topography does not allow such a solution, like at site 'B' on Fig. 6 where river-damming rock-slide had occurred in the past too (STROM, 2012a) and evidence of present slope instability could be found above this ancient headscarp (see Fig. 8) landslide monitoring and, if necessary, slope stabilization measures should be anticipated to minimize possible negative effects.

EVIDENCE OF PAST OUTBURST FLOODS EXCEEDING ANTICIPATED PMF DISCHARGE

Evidence of past outburst floods that exceeded significantly both maximal observed discharge values and PMF estimates have been found in the Naryn River basin immediately downstream from the Kambarata-1 dam site (point 'C' on Fig. 6) (STROM, 2012a) and far upstream in the Kokomeren River valley (STROM, 2012b).

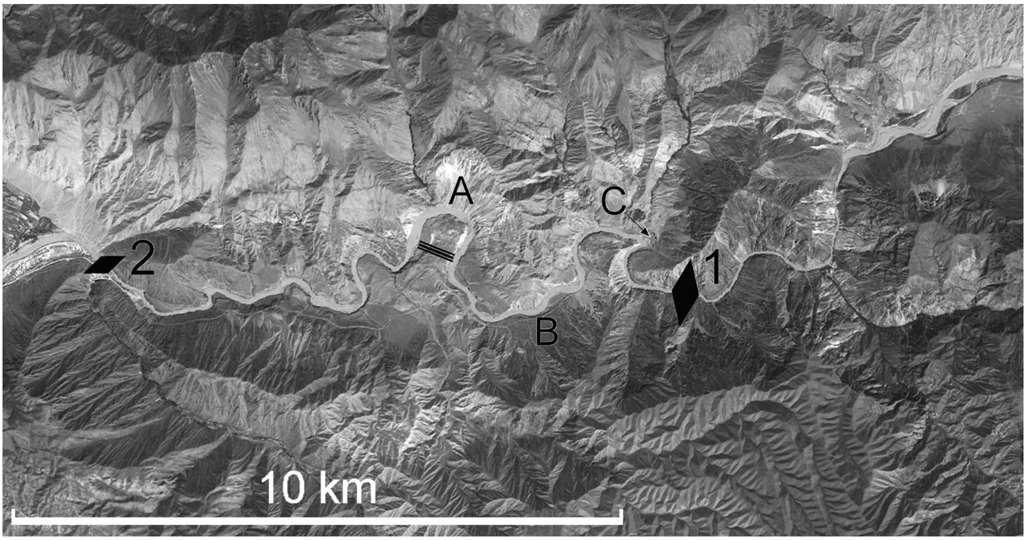

Fig. 6 - Position of the potentially unstable slopes between the Kambarata-1 & 2 dam sites. 1 - the proposed Kambarata-1 dam; 2 -Kambarata-2 dam constructed in 2009; triple black line - bypass channel under construction. Brief description of sites A-C is given in the text

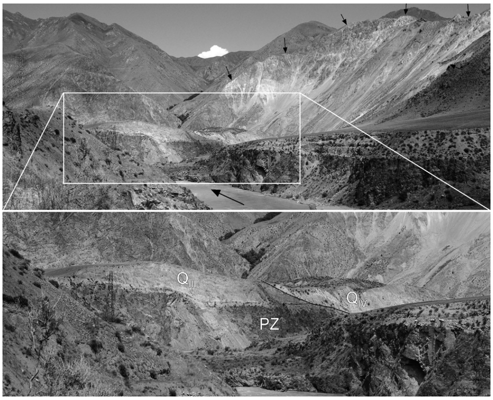

Fig. 7 - Past rock avalanche deposits between the Kambarata-1 and 2 dam sites. Headscarp marked by small arrows is shown as site 'A' on Figure 6. The younger - Q_{IV} rock avalanche deposits partially overlay those of the Q_{III} rock avalanche

At point 'C' tree trunks 40-50 cm thick were found on a right bank terrace of the Naryn River about 5 m above the mean stream level. Such trunks could be brought here by an abnormally powerful flood with peak discharge of about 6 000-7 000 m^3/sec and, possibly, up to 10 000 m^3/sec - 2-3 times more than maximal flood ever recorded in this part of the Naryn River. These estimates exceed the assumed PMF value of the Naryn River accepted for the Kambarata-1 & 2 Project. Search of possible causes of such flood revealed that an excessive discharge could be produced by breach either of a landslide-dammed lake in small tributary valley or in the large valleys of Naryn or of its main tributary - the Kokomeren River (Strom, 2012a). Similar phenomena could be anticipated in future, which require special analysis and some prevention or mitigation measures, if necessary.

One potential source is a drained lake in the Unkursay River valley - left tributary of the Kokomeren River, nearly 2 km down-stream from the existing Ak-Kiol Lake (Fig. 9). This Lower Ak-Kiol dam (41º42.4' N, 74º16.8' E,) was breached rather recently. A distinct stripe of fossilized lake algae about 15 m above the present day valley bottom indicates its single-event emptying that had released 2-3 million cubic meters of water (Strom, 2012a). The Ak-Kiol lake (41º41.1' N, 74º17' E,) that stores 2.7 Mm^3 of water (Torgoev & Erohin, 2012) being located about 85 km from the Kambarata-1 dam site, could be breached catastrophically producing flood and debris flow formation that would devastate lower reaches of the Unkursai River (Torgoev & Erohin, 2012).

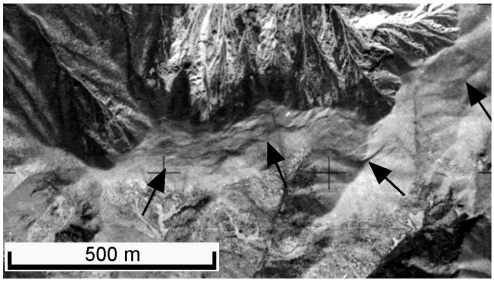

Fig. 8 - Small scarps (marked by arrows) on top of the ridge above slope 'B' on Figure 5 indicating its ongoing instability

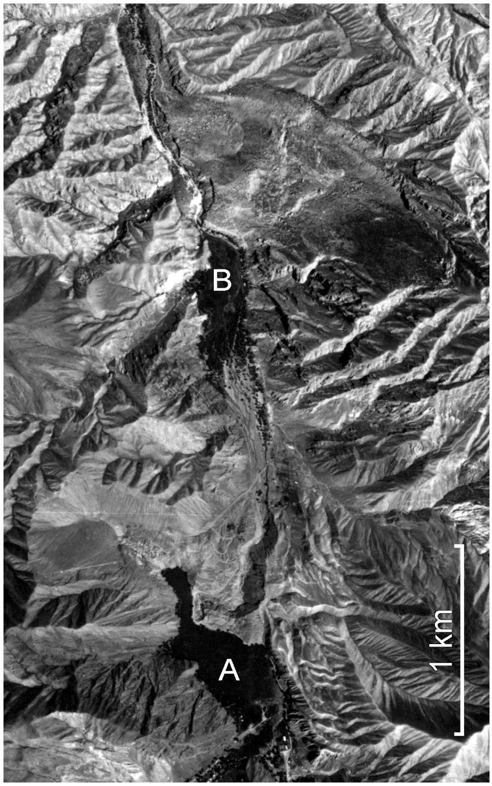

Fig. 9 - Aerial photograph of rockslide dammed lakes in the Unkursai River valley. A - the existing Ak-Kiol lake; B - swampy area of the drained Lower Ak-Kiol lake

One more relatively large Aik-Kiol rockslide-dammed lake in the valley of a small unnamed left tributary of the Kokomeren River about 55 km up-stream from the Kambarata-1 dam site (41º43.5' N, 73º57.6' E, Fig. 10) stores about 3-4 Mm^3 of water. The *ca* 220 m high Aik-Kiol dam located in hardly attainable valley have not been studied yet with such deathliness as the above mentioned Ak-Kiol dam. Its morphology shows that at present the dam is stable,

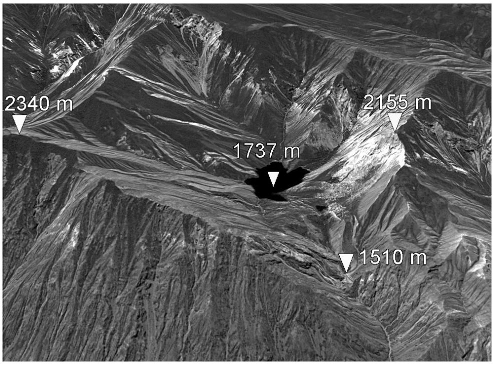

Fig. 10 - 3D view of the Aik-Kiol rockslide dammed lake about 500×700 m in size and its catchment area. Distance between points with elevations of 2340 m and 2155 m is about 2.8 km

but could be breached in case of extreme rainstorm or snow melt that could cause its overtopping.

Due to limited amount of water that could be released and significant distance from the Kambarata-1 reservoir breach of these lakes would not provide any hazard for the dam with large reservoir but should be considered for the much smaller Kambarata-2 Project. It could cause, first, the excessive sediment yield and abnormally high siltation of the shallow reservoir and, second, inflow that could exceed the existing spillway capacity.

One more potentially hazardous water body - the moraine Petrov Lake containing 65 Mm^3 of water, 39 million of which could be drained in case of dam breach (Torgoev *et alii*, 2012) is located at the glaciated source of the Naryn River. Despite its large volume, due to very large distance from the reservoirs in question (about 600 km from the Kambarata-1 dam site) its breach could hardly have a significant effect on the Kambarata dams, unless it would coincide with the extreme flood caused by rainstorm or snowmelt, which probability is rather low.

Most severe effects could be anticipated if rockslide would block main streams of the Naryn and Kokomeren Rivers, resulting in formation of a large water body dozens or even hundreds millions cubic meters in volume as it had happened here repeatedly in the past, in Late Pleistocene and in Holocene.

It could be exemplified by the Lower Aral rockslide dam (Strom, 2012b) that had blocked the Kokomeren River valley at 41º47.9' N, 74º17.3' E, about 40 km upstream from its mouth. Rock avalanche had originated on top of the ridge, moved for about 2 km towards the

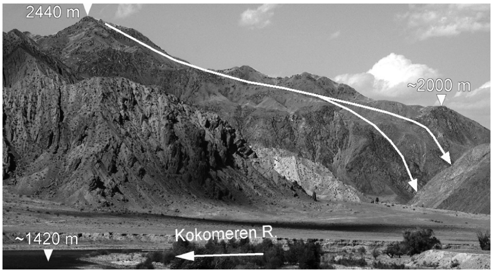

Fig. 11 - Overview of the Lower-Aral rock avalanche. White arrows show its travel path from the headscarp on top of the ridge towards the depositional zone in the more than 500 m deep gorge of Kokomeren River

valley and, finally, caved into deep gorge splitting into two parts (Fig. 11); the upstream one formed the 70-m high dam that created a lake about 12 km long storing up to 200 Mm^3 of water. Its catastrophic release years after the impoundment (which follow from the presence of laminated silt more than 5 m thick 7 km upstream) caused outburst flood with peak discharge up to 28 000-30 000 m^3/sec (Strom, 2012b).

Considering abnormally high landslide susceptibility of the area along the Naryn-Lower Kokomeren valleys that coincides with the fault zone stretching for more than 120 km between Ketmen-Tiube depression filled by the Toktogul reservoir and the Sonkul depression with the same-name lake (marked by 'T' and 'S' on Fig. 1) and its high seismic potential (Strom, 2012a; Havenith *et alii*., 2013) possibility of future large-scale slope failures upstream from the Kambarata-1 reservoir could not be excluded and must be taken into account when choosing preferable type of the dam, its height, reservoir normal and maximal operating levels and the spillway capacity.

DISCUSSION AND CONCLUSION

Both case studies, described above, as well as other examples from the same region (Asian Development Bank, 2006; Strom, 2010; Havenith *et alii*, 2013) and from other parts of the World (Costa & Schuster, 1988; Schuster & Evans, 2011), demonstrate that landslides and debris flows originating far from the dam site and reservoir area can pose a significant threat for hydraulic structures in mountain regions and that possibility of such phenomena occurrence must be taken into account in the course of dams' design. It is especially important considering centuries-long life time of many hydraulic schemes with high dams and large reservoirs. Though it could be difficult to foresee precisely what could occur within such a long-term time span, we must, nevertheless, anticipate possible negative consequences and related risks.

If potential hazards are identified and quantified with sufficient accuracy than measures aimed to mitigate or, even, to prevent negative effects could be arranged. It is very important to carry out these measures timely, which will provide maximal effect. Considering the Obi-Shur debris flows described above, construction of the protection dam (or any alternative debris flow protection activities) should have been performed prior to construction works at the Rogun dam site itself, which could prevent years-long suspension of Project implementation and significant economic losses.

Most cardinal measure is the construction of a structure ensuring free water flow in case of any stream-damming event. It could be either a bypass channel like that one across the large meander of the Naryn River shown on Fig. 6, protecting the Kambarata-1 power-house from inundation and relatively small Kambarata-2 dam from destruction by outburst flood or a diversion tunnel that was proposed in the Vakhsh River section affected by the Baipaza landslide that endanger the Baipaza HPP upstream and the Sangtuda HPP down-stream (Asian Development Bank, 2006; Havenith *et alii*, 2013). We should note that, despite real hazard posed by this landslide, construction of the tunnel have not started yet.

The design and construction of such structures is, however, quite expensive. Thus, if and where the potential "remote" hazards are identified, regular monitoring must be performed as an economically reasonable alternative. It could be based on wide use of modern remote sensing techniques such as analysis of high resolution optical space images (Sato & Harp, 2009) and radiometric (INSAR) data (Burgmann, 2000; Catani *et alii*, 2005; Colesanti & Wasowski, 2006) for regular inspection of the state-of-the-art of both large catchment areas and specific sites. Sit-specific inspections can be accompanied by airborne and/or ground-based laser scanning that provide quantitative DEM of the study area with high accuracy (Jaboyedoff *et alii*, 2012) and by ground based radiometric monitoring (Antonello *et alii*, 2004). Survey intervals should be assigned with due regard of the recurrence of hazardous phenomena and of the character of main triggering factors (i.e. rainstorms, snowmelt, river erosion, etc.). Unscheduled inspections must be performed after any extreme events that might trigger large-scale slope failures such as strong earthquakes and abnormally strong rainstorms.

Important component of such monitoring system is regular hydrological measurements in the main streams entering a reservoir. Any abnormal drop of the discharge indicates argent necessity of the catchment inspection. We should point out that, on the one hand, larger the landslide blockage is, more hazard it provides, potentially, due to larger amount of stored water. On the other hand, however, larger natural dam requires more time to infill the lake, thus allowing more time to arrange protective measures (Neshikhovskiy, 1988; Shang *et alii*, 2003; Cui *et alii*, 2009; Schuster & Evans, 2011). Besides such damming results in a significant decrease of the inflow into reservoir, thus supporting its level lowering to get more space to accommodate water delivered by outburst flood.

The most striking example is the famous Lake Sarez. Being formed in 1911 by gigantic Usoi rockslide in the remote area of Pamirs mountains it poses a potential treat to the Bartang, Pianj and Amu-Daria River valleys with population of about 5 million (UN, 2000). Till now, more than 100 years after its formation, the blockage seems to be stable with freeboard of about 38 m (Ischuk, 2011). However, in long-term perspective, considering quite complex geotechnical, seismological and hydrological situation, it is unlikely that its safety can be ensured without special protection measures allowing artificial lake level lowering. Such measures, which are high technical and expensive, could be performed only, while situation is stable. If, due to any reason, hazard of dams' breach will increase, there could be no time to carry out long-term construction works at this hardly attainable area. Besides regional security matters, pendency of the Sarez Lake problem could prevent development of any large hydraulic scheme in the lower reaches of the Pianj River.

Case studies described above demonstrate that study of the potentially unstable slopes that can produce river damming down-stream from the HPP and upstream from the reservoir within the catchment area must be performed to ensure safety of hydraulic schemes and that such surveys must be included as mandatory activities in the corresponding national and international guidelines.

REFERENCES

ANTONELLO G., CASAGLI N., FARINA P., LEVA D., NICO G., SIEBER A.J. & TARCHI D (2004) - *Ground-based SAR interferometry for monitoring mass movements*. Landslides **1**: 21-28.

ASIAN DEVELOPMENT BANK (2006) - *Tajikistan: emergency Baipaza landslide stabilization project.* Completion Report Project 36233.

BESSTRASHNOV V., ZHIRKREVICH A., STROM A. & SHILINA E. (2013) - *Influence of landslide and glacial blockages on the Rogun HPP Safety.* In: C. MARGOTTINI *ET ALII* (eds.). *Landslide science and practice.* Springer-Verlag Berlin Heidelberg. **6**: 91-96.

BURGMANN R., ROSEN P.A. & FIELDING E.J. (2000) - *Synthetic aperture radar interferometry to measure Earth's surface topography and its defor-mation*. Annual Review of Earth and Planetary Sciences, **28**: 169-209.

CATANI F., CASAGLI N., ERMINI L., RIGHINI G. & MENDUNI G. (2005) - *Landslide hazard and risk mapping at catchment scale in the Arno River basin*. Landslides, **2**: 329-342.

COLESANTI C. & WASOWSKI J. (2006) - *Investigating landslides with space-borne Synthetic Aperture Radar (SAR) interferometry*. Engineering Geology, **88** (3-4): 173-199.

COSTA J.E. & SCHUSTER R.L. (1988) - *The formation and failure of natural dams.* Geol. Soc. Am. Bull., **100** (6): 1054-1068.

CUI P., ZHU Y., HAN Y., CHEN X. & ZHUANG J. (2009) - *The 12 May Wenchuan earthquake-induced landslide lakes: distribution and preliminary risk evaluation*. Landslides, **6**: 2009-223.

EVANS S.G., BISHOP N.F., SMOLL L.F., MURILLO P.V., DELANEY K.B. & OLIVER-SMITH A. (2009) - *A re-examination of the mechanism and human impact of catastrophic mass flows originating on Nevado Huascarán, Cordillera Blanca, Peru in 1962 and 1970.* Eng. Geol. **108**: 96-118.

HAVENITH H-B., ABDRAKHMATOV K., TORGOEV I., ISCHUK A., STROM A., BYSTRICKY E. & CIPCIAR A. (2013) - *Earthquakes, landslides, aams and reservoirs in the Tien Shan, Central Asia*. In: C. MARGOTTINI *et alii* (EDS.). *Landslide Science and Practice*. Springer-Verlag Berlin Heidelberg. **6**: 27-31.

ISCHUK A.R. (2011) - *Usoi Rockslide Dam and Lake Sarez, Pamir Mountains, Tajikistan*. In: EVANS S.G., HERMANNS R, SCARASCIA-MUGNOZZA G. & STROM A.L. (eds.), Natural and Artificial Rockslide Dams. Lecture Notes in Earth Sciences, **133**: 423-440.

JABOYEDOFF M., OPPIKOFER T., ABELLÁN A., DERRON M-H., LOYE A., METZGER R. & PEDRAZZINI A. (2012) - *Use of LIDAR in landslide investigations: a review.* Nat Hazards, **61**: 5-28.

KOTLYAKOV V.M. (ED) (2006) - *Glaciation in Northern and Central Eurasia at present.* Moscow, Nauka, ISBN 5-02-035344-2: 482 pp. (in Russian).

MULLER L. (1964) - *The rock slide in the Vaiont valley.* Rock Mech. and Eng. Geol., **6**: 148-212.

NESHIKHOVSKIY R.A. (1988) - *Floods on rivers and lakes.* Leningrad, Hydrometeoizdat (in Russian).

OSIPOVA G.B., TSVETKOV D.G., SCHETINNIKOV A.S. & RUDAK M.S. (1998) - *Catalogue of surging glaciers of the Pamirs*. Materials of glaciological investigations, **85**: 3-136 (in Russian).

PARONUZZI P. & BOLLA A. (2012) - *The prehistoric Vajont rockslide: An updated geological model.* Geomorphology, **169-170**: 165-191.

PLAFKER G. & ERIKSEN G.E. (1978) - *Nevados Huaskaran avalanches, Peru.* In: VOIGHT B. (ED.) Rockslides and Avalanches, v. **1**, Elsevier, Amsterdam: 277-314

SATO H.P. & HARP E.L. (2009) - *Interpretation of earthquake-induced landslides triggered by the 12 May 2008, M7.9 Wenchuan earthquake in the Beichuan area, Sichuan Province, China using satellite imagery and Google Earth*. Landslides, **6**: 153-159.

SCHUSTER R.L. & EVANS S.G. (2011) - *Engineering Measures for the Hazard Reduction of Landslide Dams* In: EVANS S.G., HERMANNS R., SCARASCIA-MUGNOZZA G., STROM A.L. (EDS.). *Natural and Artificial Rockslide Dams.* Lecture Notes in Earth Sciences, **133**: 77-100

SEMENZA E. (2010) - *The story of Vaiont told by the geologist who discovered the landslide*. K-flash, ISBN 978-88-89288-02-3.

SHANG Y., YANG Z., LI L., LIU D., LIAO Q. & YANGCHUN W. (2003) - *A super-large landslide in Tibet in 2003: background, occurrence, disaster, and origin*. Geomorphology, **54**: 225-243.

STROM A (2010) - *Landslide dams in Central Asia region*. Journal of the Japan Landslide Society, **47** (6): 309-324

STROM A. (2012a) - *Effects of rockslides and rock avalanches on hydropower schemes in the Naryn River valley*. In: EBERHARDT E. *et alii* (EDS). *Landslides and engineered slopes. Protecting society through improved understanding.* Taylor & Francis Group, London. **2**: 1867-1872.

Strom A. (2012b) - *Geological prerequisites for landslide dams' Disaster assessment and mitigation in Central Asia*. In: Wang F. *et alii* (eds.). *Progress of geo-disaster mitigation technology in Asia, environmental science and engineering*. Springer-Verlag Berlin Heidelberg: 17-53.

Strom A.L. & Abdrakhmatov K.E. (2004) - *Clustering of large rockslides: the phenomenon and its possible causes.* In: Lacerda W.A., Ehrlich M., Fontoura A.B. & Sayao A. (Eds.). *Landslides: evaluation and stabilization.* Taylor and Francis Group, London, 317-320.

Torgoev I.A. & Erochin S.A. (2012) - *Debris flow risk assessment for possible Ak-Kiol outburst (Kyrgyzstan)*. In: Chernomorets S.S (ed.), *Debris flows: disasters, risk, forecast, protection.* Proceedings of the Second Conference dedicated to 100th anniversary of. S.M. Fleishman. Moscow, 17-19 October 2012: 91-92 (in Russian).

Torgoev I., Havenith H-B, & Strom A. (2013) - *Impact of 300-t blast on unstable slope near the Kambarata-2 HPP site, Kyrgyzstan.* In: Margottini C. *et alii* (eds.). *Landslide science and practice*. Springer-Verlag Berlin Heidelberg, **6**: 37-42.

UN International Strategy for Disaster Reduction (2000) - *Usoi landslide dam and Lake Sarez. An assessment of hazard and risk in the Pamir Mountains, Tajikistan.* ISDR Prevention Series, New York and Geneva, No **1**.

