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UTILISATION OF THE DATA ON ROCKSLIDE DAMS FORMATION AND STRUCTURE FOR BLAST-FILL DAMS DESIGN

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INTRODUCTION

Construction of blast-fill dams is a promising, but risky technology. The traditional methods of both embankment and concrete dams construction, when the structure is erected slowly - dumper by dumper - allow to change, if necessary, either the material or technology or, even, the design. But the blast-fill dam, regardless of is it constructed by pin-point blast or by artificial rock avalanche (Korchevsky, 2004) would be erected "in one gulp".

The most important parameters of the blast-fill dam that must be achieved after the explosion and the subsequent rock mass failure are:

- height of the dam and of the lowermost part of its crest (the effective dams height) in the first place; the latter should be at least 12-15 m higher than the designed reservoir water level (Kolichko, 2004);
- up- and downstream limits of the blockage, which should not extend beyond the designed bounds in order not to block inlets and outlets of the headrace and tailrace tunnels;
- homogeneity and the designed permeability value of the dams body.

If any of the above parameters will not achieve the designed values (i.e. will be lower or higher, depending on the particular parameter) it will be difficult and costly to improve the situation.

That is why it is so important to consider any possible complications beforehand. It is obviously that the development of a new technology requires extensive investigations, numerical and physical modelling in particular. But to simulate such a complex process, either numerically or physically, we must know its nature, which is not fully understood yet. More over, any model obviously simplifies the real process, while some aspects, that seems to be negligible, may have a significant effect on the possibility of dams erection in the specific conditions of the particular dam site. That is why we believe that comprehensive study of the natural rock slope failures of the same size and shape as the designed dam should be considered as the most informative method providing important and reliable information for the designers.

Hereafter we will focus on several problems associated mainly with the dams formed by the artificial rock avalanches, since just this technology utilise processes very similar to those that take place during large-scale rock slope failures. Besides it allow construction of very large structures, such as the designed Kambarata-1 dam, comparable with large-scale natural rockslides and rock avalanches.

FACTORS AFFECTING THE DAM HEIGHT

ACROSS-VALLEY DEBRIS DISTRIBUTION

The across-valley rock avalanche debris distribution ideal for dam construction corresponds to the case when the entire crest height is the same (Figure 1-A). However it is a very rare case of the natural blockages and usually one can observe significant non-uniformity of such dam crests. Most of the largest natural blockages, such as the Usoy in the Pamirs (Gaziev, 1984; *Usoy Landslide Dam*, 2000), Köfels in the Tirolean Alps (Erismann, 1989), Djashilkul in the Northern Tien Shan (Abdrakhmatov & Strom, 2006) and many others are much lower at their proximal parts rather than at the distal ones (Figure 1-B). On the contrary, many others, such as giant Kokomeren rockslide in the Tien Shan, for example (Strom, 1998) have been dissected at their fronts due to their distal parts prominent lowering (Figure 1-C). Some times the excess of the highest part of the dam over the lowest one could be

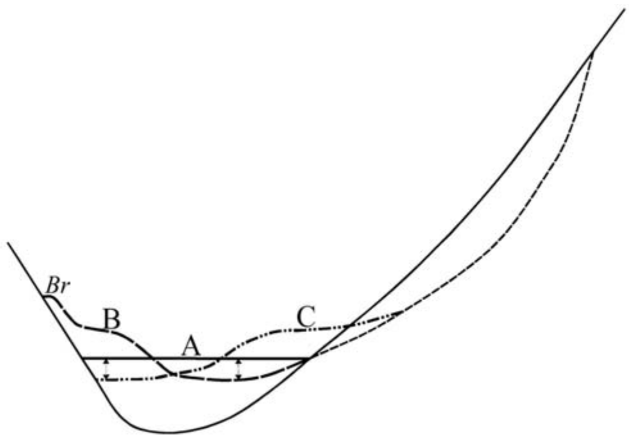

*Figure 1 - Across-valley rock avalanche debris distributions. A – even crest level typical of the embankment dams; B – distally raised profile typical of primary avalanches (Strom, 1996) (**Br** - brandung); profile with proximal accumulation typical of secondary or spread rock avalanches (Strom, 1996)*

about 25-30% of the average dam height if not more. Considering rock avalanche motion as a motion of a quasi-liquid media one can assume that it either pass the equilibrium position or does not reach it. From the construction point of view it means that exploded and collapsing rock mass can either gain too much momentum or not reach its optimal value. In both cases the designed dams' height may be not obtained at the lowermost part of its crest that would require additional works to rise the crest level.

The above unfavourable pattern can be even strengthen by the *brandung* phenomenon first described by HEIM (1932) and very well exemplified at numerous cases in the Karakoram (HEWITT, 2002) and other regions. Enormous tongues of debris that rise above the average rockslide level for dozens and even hundreds of meters (*Br* on figure 1) incorporate large parts of their entire volume that should be excluded from the designed balance between the exploded and emplaced rock mass. Large *brandung* about 10^5 m^3 in volume was found at the Gol-Ghoro rock avalanche in the Indus River (HEWITT, 2002). May be the most expressive case, that can be classified as a *super-brandung* is the Avalanche-Lake rock avalanche (EVANS *et alii*, 1994) in the Mackenzie Mountains where a large portion of debris (5×10^6 m^3) was thrown out from the gorge on a shelf about 600 m above dam surface. We assume that it was really a throw and that not only several fragments of rock avalanche debris that were found beyond the limits of the main splash (see EVANS *et alii*, 1994, figure 14) but the whole rock mass that now rests on a shelf moved along the ballistic trajectory. Since upward component of debris motion could not decrease immediately after it "climbed" on the 640-m high slope its further motion over the shelf should be ballistic rather then sliding along the shelf.

It is evidently that further investigations are necessary to understand causes of various across-valley debris distributions and to suggest methods of maximal possible flattening of the blockage crests.

SECONDARY ROCK AVALANCHES

The most discussed cause of the dam height decrease is the lateral spreading of debris along the river valley (KORCHEVSKY & PETROV, 1989, KORCHEVSKY, 2004). It can lead to double negative effect – lowering of the dam at first and, secondly, affecting various structures up- and downstream from the dam site, blocking of the inlets and outlets of the headrace and tailrace tunnels in particular.

One of the main mechanisms of such spreading, at least in the narrow river gorges where blast-fill dams can be constructed, is the secondary rock avalanche formation (STROM, 1996). This phenomenon (Figure 2) can be defined as an ejection of debris portion from the deposits accumulated at the scars' foot due to abrupt momentum transfer when the entire sliding mass collides with an obstacle.

The latter can be either opposite slope or valley bottom or, as discussed bellow, other part of the collapsing rock mass. In many cases the amount of debris involved in the secondary avalanche motion is more than a half of the total rockslide volume and much bigger than visible dimensions of the secondary scar on the initial blockage slope. The latter fact supports the assumption that the initial failure and secondary avalanche formation are the consecutive stages of the united indivisible process. Additional hazardous pattern of such type of rock slope failures is the possibility of secondary avalanche motion practically at a right angle to the direction of the initial failure (see figure 2). In other words, large portion of debris can move at a very long distance along the riverbed. The expressive cases could be found in the Tien Shan – South-Karakungey, Snake-head, Kiol-say, Karasu rockslides (STROM, 1996; STROM, 2006), in the Mackenzie Mountains – Nozzle and U-turn rockslides (EISBACHER, 1979) and in other mountainous regions.

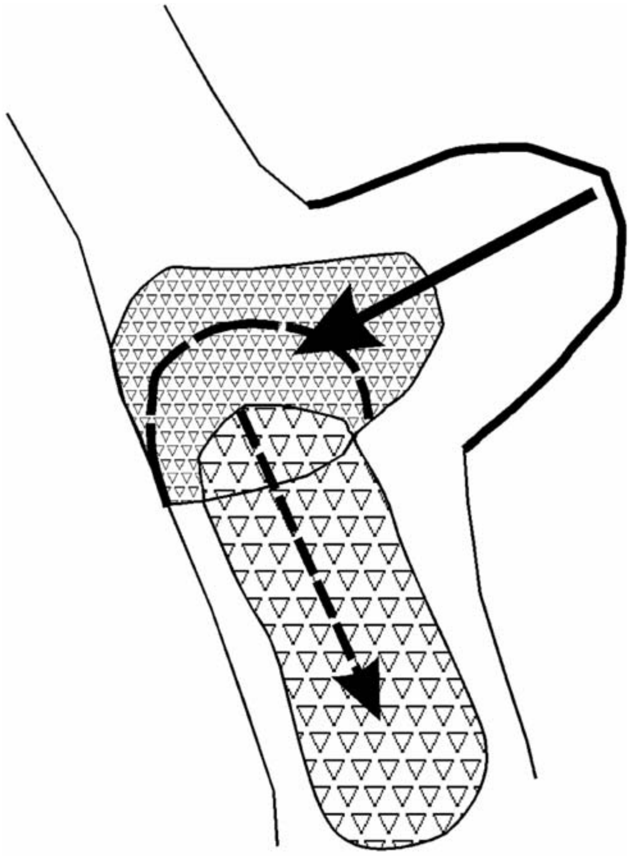

Figure 2 - General scheme of the secondary rock avalanche formation. Amount of debris involved in the secondary rock avalanche can exceed the nominal volume of the secondary scar

As mentioned above, sometimes secondary rock avalanches had been formed by the collision of debris that descended from the concave slopes of the circus-shaped gullies. It can be exemplified by the Chaartash-1 & 2 rock avalanches (STROM, 1998) where large amount of collapsing rocks that descended from the opposite slopes of the short gorges collided each other at their bottoms creating tremendous – up to 5-7 km long – secondary avalanches (Figure 3).

As far as bow-shaped sections of river gorges with concave slopes are considered as favourable conditions for blast-rockslide dam construction (Korchevsky, 2004) the possibility of such process should be taken into consideration and analysed, and measures preventing extra-rapid motion of a significant portion of the exploded rock mass should be envisaged.

We hypothesise that origin of the above *brandung* features can be caused by the similar momentum transfer as in the secondary avalanche cases. Anyway, both effects reduce dam effective height.

FACTORS AFFECTING DAM PERMEABILITY AND EROSIONAL RESISTANCE

DUAL INTERNAL STRUCTURE

One of the typical features of large rockslide dams is their distinct dual internal structure. Almost in all cases when such dam composition can be observed in the outcrops one can see intensively comminuted debris of its lower part overlaid by large angular boulders and/or huge blocks of rocks that were emplaced with relatively small extent of disintegration. It was described in the Alps at Flims and Köfels (Erismann, 1989), in Karakoram at the Gol-Ghone, Chalt and Haldi rockslides (Hewitt, 1999; 2006), at the numerous cases in the Tien Shan (Gerasimov, 1965; Strom, 1994; Abdrakhmatov & Strom, 2006), in the Northern Caucasus (Strom, submitted), and can be observed in many other regions as well.

Such composition governs at a high extent both dam permeability and its resistance in case of overtopping. The first peculiarity is well exemplified by the famous Usoy dam where almost entire seepage takes place through the uppermost blocky unit about 100-m thick (Ischuk, 2004), while the lower 400 meters are practically impermeable. The same feature characterises the Great Almaty Lake in Northern Tien Shan (Bochkariov, 2004).

At the same time large blocks and boulders on the dam surface form a carapace that prevents its erosion in case of the overtopping. However, abrupt difference of the upper and lower parts permeability may lead to the internal erosion if high discharge through the hollows in the former one will directly affect the underlying comminuted debris.

PROPERTIES OF THE INTERNAL CORE

Distinct difference of the grain-size composition of the upper/external and lower/internal parts of rockslide dams allows to analyse them separately. Study of the grain-size composition of the material sampled from the lower – comminuted parts of deeply incised natural dams shows that it fits well to the Rosin-Rammler (Weibull) distribution (Weibull, 1951):

$$F(x) = 1 - exp[-(x/x_0)^n] \qquad (1)$$

where x_0 and n – parameters of distribution.

Parameter n characterises “range” of the grain-size composition: the smaller its value is, the more variable in size fragments are that ensures dense compaction of debris. In the studied cases coefficient n vary from 0.805 to 0.376, which corresponds to a very “wide” composition, even wider than that for blasted rock (about 0.8, on an average). It can explain low permeability of the internal parts of large rockslide dams. Further investigations are required, however, to obtain more representative data, since the amount of sampled debris is often rather small – up to several kilograms only.

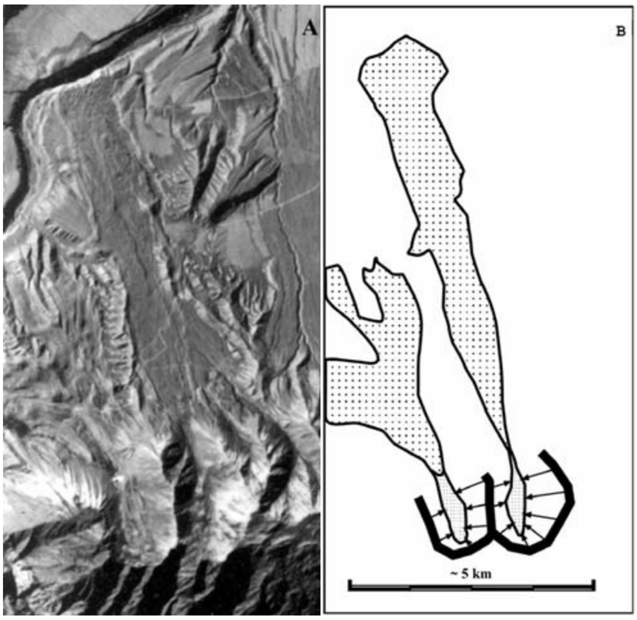

Figure 3 - Secondary avalanches of the Chaartash 1 & 2 rockslides. A – fragment of the high-resolution space photograph; B – scheme demonstration relationships between rockslides scars, initial accumulations (small specks) and secondary rock avalanches (medium specks)

CONCLUSIONS

Comprehensive study of the morphology, internal structure and mechanism of formation and destruction of natural rockslide dams provides detail and reliable data that must be utilised for the design of blast-fill dams erected by the artificial rock avalanches. Such investigations allow to give proper weight to such peculiarities of the related phenomena that could be hardly reconstructed by the small-scale mechanical modelling. They should be used as the grounds of the numerical modelling that must consider (and explain?) all observed phenomena.

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