DOI: 10.4408/IJEGE.2006-01.S-10

THE STABILITY OF THE FLIMS ROCKSLIDE DAM

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LANDSLIDE DAMS IN THE ALPS

The historic and prehistoric rockslide dams in the Alps give a good indication about the possible evolution and the dam stability. The two extremes are either an early break of the dam, releasing all the water in a catastrophic flush-flood, or a total filling of the basin by sediments. Between these extremes exist many possibilities. The survival of a lake in most cases is only a temporary condition. Nevertheless ABELE (1974) counts 33 remaining lakes among the 285 rockslide sites he discusses. This means a rate of about 12%.

The probability of an outburst decreases with time after the event. In historic time several flood disasters in the Alps have been documented (MONTANDON, 1933). Apparently about half of the dams showed an early and complete breakdown.

A typical example is the Bisaca flood in 1515 (EISBACHER & CLAGUE, 1984). On 30 September 1513 a mass of 10 - 20 x 10^6 m^3 collapsed and blocked the Brenno river. It dammed a lake of about 100 x 10^6 m^3 and drowned two hamlets. It was not before 20 May 1515 that during the spring snowmelt the dam eroded and collapsed. The resulting flood destroyed the city of Biasca and swept down the Ticino valley to Bellinzona, still causing a huge wave in Lago Maggiore. About 600 people lost their lives. Today, no geological evidence for the flood event and for the existence of the former lake can be found.

Morphologic indications show that a number of rockslide lakes have emptied in several steps. ABELE (1974) enumerates many examples of delta and lake sediments in a stepwise arrangement, indicating a multiphase evolution of the lakes. One of these examples is the Flims rockslide, described here more in detail.

THE FLIMS ROCKSLIDE

The Flims rockslide in the Swiss Alps is the biggest landslide deposit known in the Alps. Its volume is estimated to be 8 km^3, covering a surface of about 52 km^2 (POSCHINGER *et alii*, 2005). The long history of investigations has been resumed by the author (loc.cit.). In the recent years a new impetus has come into the study of the Flims rockslide. One important finding was the radiocarbon dating of the rockslide, thought to be late glacial until then, to about 8200 – 8300 yrBP (POSCHINGER & HAAS, 1997, POSCHINGER *et alii*, 2005). This means a warm climate (Boreal) without any direct glacial influence as a trigger.

THE ROCKSLIDE EVENT

Mechanisms responsible for the rockslide material

Without any doubt the rockslide happened "in one great stroke", as already ascertained by HEIM (1883). The sedimentary layering of the Jurassic and Cretacious limestone is almost parallel to the slope and inclined southward at an angle of about 20°-35°. The whole Flimserstein mountain as the source area of the rockslide (Figure 1) is not built up by a consequent sedimentary sequence, but is tectonically shaped by several parallel folds and by imbricate thrusts (OBERHOLZER, 1933). Nevertheless, the general main structure parallel to the slope is striking.

On both sides the rockslide scar is limited by rock cliffs more or less parallel to the direction of movement. These cliffs worked as a lateral confinement, at least in the first stage of the movement. The special rockslide material found today in the Rhine gorge may be partly due to this confinement.

The whole moving rock mass did not spread out far to both sides, but kept together its main body. That is why the primary rock structure

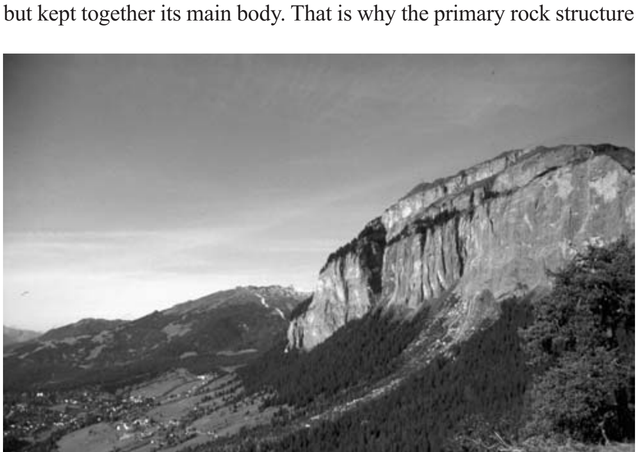

Figure 1 - Scarp of the Flimserstein as the source are of the rock slide. The pasture area around the village of Fidaz is sub-parallel to the sliding plane. In the area between the forest and the pastures in 1939 a rockfall destroyed a children home killing 18 persons. Several other historic rockfalls from the cliff are reported by EISBACHER & CLAGUE (1984)

in many places is still preserved. Nevertheless, the rock is entirely crushed (Figure 2). The degree of fracturing differs from place to place. The undulating form of the slide surface must have caused a first destruction during the motion (ERISMANN, 1988). Also the existence of important steps, some higher than 50 m, within the slide surface must have caused a further internal destruction of the sliding mass. The maximum deformation however happened during the impact of the rock mass onto the opposite slope. Now, the resulting facies differs according to the specific local stress attained during the event. In many places a small scale "jigsaw-puzzle" has been produced, still preserving the original structure. This general structure is intersected more or less densely by deformation planes and -zones. Along those the limestone has been grinned to finest gouge. Often these planes are sub-parallel to the former sedimentary layering (WASSMER *et alii*, 2004). One reason for the creation of these deformation planes may be the sheet on sheet movement as described by Wassmer in POSCHINGER *et alii* (2005). An even more probable reason has been proposed by ERISMANN (1977) for the example of the Köfels rockslide in Tyrol: The lower parts of the moving mass will hit the opposite slope much earlier than the higher parts. That is why during the impact the higher parts have to travel a longer distance and will keep on moving while the lower part has already more or less stopped. This may happen in only few steps as assumed for Köfels, or in many steps or almost progressively as suggested by the author for Flims.

Only the uppermost part of the rockslide mass shows the typical facies of a rockslide, a chaotic blocky one with finer grained matrix and with low density. Wassmer (loc.cit.) called it "granular facies". This facies is due to the lack of confinement of the material and by the disintegration of the top of the sliding mass. Also an effect of relaxation as a result of the preceding shock wave is probable. The thickness of this facies is hard to predict, but in the outcrops in the frontal part it rarely exceeds 10-20 m.

The material

As already mentioned by WASSMER *et alii* (2004), the different facies of the rockslide deposits have been important for the dam stability. The topmost blocky chaotic facies is clearly to be distinguished from the compacted, dense rockslide masses and especially from the "jigsaw-facies". The latter shows according to own investigations a broad spectrum concerning the degree of crushing with all transitions. The blocky facies has a very high permeability and due to its high content of not consolidated fines it is easy to erode, as on the surface, as by subrosion in the underground.

More delicate is the estimation of the stability of the "jigsaw-facies". In any degree of fracturing it is completely dissected by dense joints (Figure 2). With few exceptions the slide mass has not been cemented and so can not be called a "breccia". These rare exceptions are either matrix supported breccias or grain supported breccias. Real matrix supported breccias occur within internal shear zones. Rockslide components up to some centimetres are embedded within finest detritic rockslide material. They are to be found mainly

Figure 2 - Crushed jigsaw facies of the rock slide material. The components have perfect fitting, but are completely loose and can be digged out by hand

at the front and at the bottom of the slide mass. Grain supported breccias are mainly on top of the slide mass. They can be rather coarse and not only include rockslide components, but sometimes also fluvially well rounded pebbles.

The permeability of the "jigsaw-facies" may be restricted by two facts. First, the gauge along the deformation planes is very fine and may act as an aquitard. Secondly, the particles have a close "grain to grain" contact with exactly fitting boundaries (Figure 2). So, the space between the particles is restricted. Nevertheless, set under water pressure, also the jigsaw-facies is due to its high degree of fracturing quite permeable. But it is very important that the special structure impedes a strong internal erosion. This material is not easy to erode and especially for subsurface water there is almost no chance to transport important amounts of solids.

THE TRACES OF THE LAKE AND OF ITS BREAKTHROUGH

The Flims rockslide has dammed two important lakes and several small lateral ponds (POSCHINGER & KIPPEL, 2006). The biggest lake was Lake Ilanz with a length of about 24 km, an estimated surface of 27 km^2 and a volume of about 1.5 km^3. These figures refer to an assumed maximum lake level of about 820 m a.s.l. This level is confirmed by many morphological traces and by lake sediments (Figures 3, 4).

The smaller Lake Versam was dammed at a level of 880 m a.s.l. and had a length of about 5 km. According to the gravel and sand layers found at the plain of Parstogn high above the Rabiusa river, this smaller lake was completely filled up with sediments.

In the literature many speculations about the life of Lake Ilanz and especially of its "death" are made. The typical lake sediments in the centre of the Lake Ilanz basin near Rueun have a thickness of 20-30 m. As concluded in POSCHINGER *et alii* (2005) the sedimentation must have kept on for many years, perhaps even for more than 1000 years. This sedimentation must not concern the lake in its full extension, but may refer to a remaining smaller lake, too. Several authors

Figure 3 - Delta sediments of Laax. Topset and foreset are clearly developed. The delta sediments and the corresponding plain indicate a lake level of about 820 m

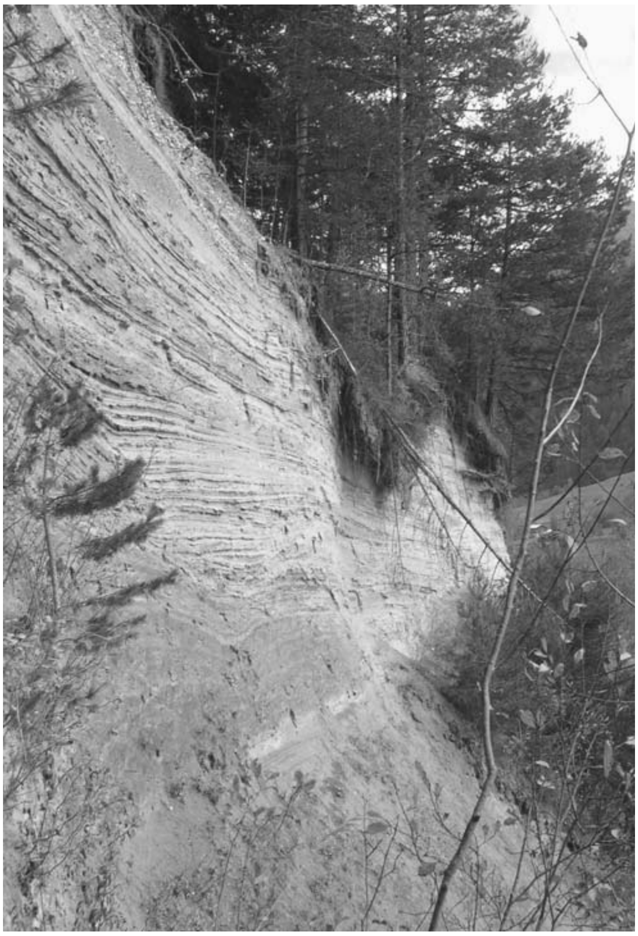

Figure 4 - Lake sediments of Lake Ilanz near Schiedberg. The whole sediment pile has more than 18 m thickness and indicates a longer lasting lake sedimentation at this level

(e.g. Abele, 1974) assumed a complete and instantaneous break of the dam with catastrophic circumstances. Almost all refer to the huge erosion- and floodplains (Figure 5), stretching over more than 6 km from Northeast of Versam until Reichenau or even further to the East. Obviously, the morphological features related to those have not yet been studied in detail. The best description until now was made by Abele (1974) who differed three different levels of terraces. Own field investigations showed that at least 5 and probably even more levels can be mapped. The top of the floodplain has a strikingly constant inclination of about 2-2.5° (4%). The flood plain spreads out laterally up to more than 1 km. It is built up in its proximal part by a top of well sorted and stratified fine angular gravel and sands, laying over coarse boulders of a typical debris flow.

In the distal part near Reichenau the top is built up by coarse blocky material. There, the floodplain cuts through the horizontal surface of the "Bonaduz gravel" (Poschinger *et alii*, 2005). This indicates that the surface of the Bonaduz gravel must have been older than the flood event. The coarse debris can be found about 13 km downstream almost until Chur, where the sediments begin to merge with younger alluvium of the Rhine river. The volume of the material transported by the flood event is hard to estimate, as about nothing is known about its thickness. Locally it is only a thin cover of debris on top of the eroded rockslide mass, locally it has replaced the Bonaduz gravel in a thickness of more than 20-30 m. A very rough estimation gives a volume of about 50 x 10^6 m^3.

Quite early after the first large flood the Rhine river must have found his track more or less along the actual riverbed. Only few erosion features are found within the floodplain. Along the actual Rhine river at least 5 levels of important erosive and/or accumulative terraces can be mapped. Obviously they represent thresholds of the barrier during its further erosion. It is striking, that also within the basin of Lake Ilanz several important levels of deltas indicate a stepwise drainage of the lake.

Figure 5 - View from Trin towards SW over the rockslide deposits (forested hills in the centre) to the floodplain (arrows) of Ransun (Ra), Zault and Dabi. The floodplain is related to the outbrake of Lake Ilanz

RECONSTRUCTION OF THE EVENT

Several phenomena indicate that Lake Ilanz did not empty in once. Especially the existence of the pronounced erosional levels are hardly to imagine for one single event. Furthermore the apex of the large floodplain refers clearly to the altitude of 810-820 m a.s.l. and no lower starting point of a really important deposition is to be found. In case of a disastrous break of the whole dam in one great event an important sedimentation should also refer to lower levels. Nevertheless, the process started without doubt with one major breakage of the uppermost part of the dam, releasing enormous amounts of water.

This event was responsible for the creation of the debris flow sediments with coarse boulders in a first stage. The layered finer gravel on top of the debris flow sediments must be referred to a later stage of the development, probably with conditions of a hyperconcentrated flow.

Morphological hints give a maximum lake level of about 820 m a.s.l. Higher levels up to about 930 m cannot be excluded (Figure 6). A level of 1170 m however, postulated recently by WASSMER *et alii* (2004), lacks any realistic geological or morphological proofs. BASTIAN (2005) has calculated a lake volume of 1.89 km^3 for the level of 820 m. The corresponding lake surface of 25 km^2 means a release of 25 x 10^6 m^3 of water in first instance for each metre in altitude. The minimum remaining lake level after the first breakage is represented by the layered silt at 760 m a.s.l. (Figure 4). This "Lake Ilanz$_{760}$" still had a length of 15 km, but its volume only attained about 0.2 km^3. So, even if the level reduced only about 28 % of its total height, the water volume released was probably about 1.7 km^3 or almost 90 % of the whole lake.

Most likely it was the chaotic blocky facies on top of the slide mass that was easily eroded, but it is not known if this facies really was 60 m thick. It must be assumed that subrosion as a consequence of heavy seepage within this facies played an important role for the first breaking. The lower part of the dam was built up by the dense "jigsaw-puzzle" facies that is evidently more resistant. The erosion probably also cut into this facies, but with the breach getting longer and longer, with the discharge reducing with the reduced lower lake surface and with the material harder to erode the breakage must have come to a stop. The thickness of the silty sediments witness that it stopped there for a longer time. The terraces indicate later on a stepwise further proceeding of the erosion down to the actual river bed at a level of 610 m a.s.l., so further 150 m down.

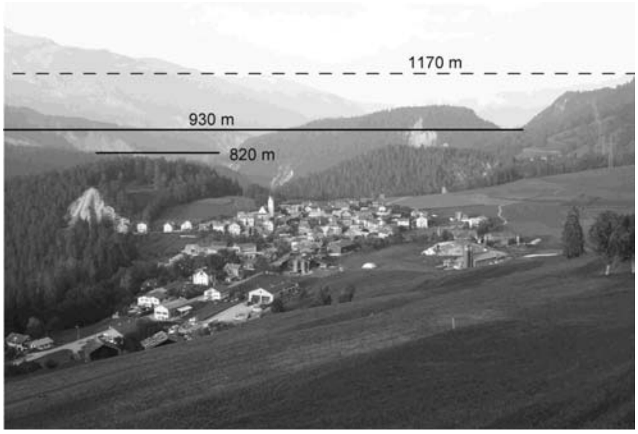

Figure 6 - View in downstream direction (East) to the remnants of the rock slide barrier. In the foreground is the village of Valendas. A maximum lake level is assumed to have reached at least 820m, but not more than 930 m. The postulated level of 1170 m is high up in the air and accordingly has no possible dam

CONCLUSIONS

The example of the Flims rockslide shows that not only the total brake of the rockslide dam may cause great flood disasters. Looking also to other rockslides in the Alps it is obviously possible to have a first breakage of the topmost part of the dam. Due to the high volume of water concerned in these parts, the release of water and sediments is important and gives a disastrous flood. For Flims the structure of the rockslide dam with its jigsaw facies in the central part was probably important for the stability. This shows that knowledge about the internal structure of a rockslide dam in question is an important clue to the assessment. Unfortunately, in unbroken condition of the dam this is very difficult to investigate.

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