HAZARD PREVENTION USING FLEXIBLE MULTI-LEVEL DEBRIS FLOW BARRIERS

PROTECTION AGAINST DEBRIS FLOWS BY INSTALLATION OF 13 FLEXIBLE BARRIERS IN THE MILIBACH RIVER (CANTON BERNE, SWITZERLAND)

Corinna Wendeler, Axel Volkwein [1], Andrea Roth[2], Beatrice Herzog[3],
Nils Hählen[4], Marc Wenger[5]

ABSTRACT

The villages Hasliberg, Reuti and Meiringen in Canton Berne, Switzerland, were affected by flood and debris flow events resulting from unusually large rainfall in August 2005. The damage potential is large, necessitating immediate action. Access problems and environmental concerns in the debris flow source area were not possible for a variety of reasons. A promising solution consisting of multiple ring-net barriers was proposed as a potentially viable mitigation measure. Because experience with such nets for debris flows is limited, laboratory tests were performed. The results of the laboratory tests provided insight on the proper design and support the general concept. Close co-operation between the scientific team of the WSL, an industrial partner and cantonal authorities during the investigations led to a consistent and technically plausible solution within a relatively short time. These multiple barrier system will be realised in 2007.

Keywords: debris flow, ring-net protection, multilevel barriers, laboratory tests.

LOCAL SITUATION

The Milibach River originates in the Gummen Region in the water shed between Oberhasli and Canton Obwalden (Fig. 1). It flows from the east through the Hasliberg settlement and – after a deep canyon– into the Aare River.

1 Swiss Federal Research Institute for Forest Snow and Landscape WSL, 8903 Birmensdorf, Switzerland, Phone: +41 44 7392111, wendeler@wsl.ch
2 Fatzer AG Geobrugg Protection Systems, 8590 Romanshorn, Switzerland, Phone +41 71 46681-55, Fax -50, andrea.roth@geobrugg.com
3 Herzog Ingenieure, Promenade 75, 7270 Davos Platz, Switzerland, Phone +41 81 41531-15, Fax -31, herzog@herzog-ingenieure.ch
4 Tiefbauamt Kanton Bern, Oberingenieurkreis I, Schlossberg 20, 3601 Thun, Switzerland, Phone +41 33 2251077, Fax -70, nils.haehlen@bve.be.ch
5 B-I-G Büro für Ingenieurgeologie AG, Dorfstrasse 10, 3073 Gümligen, Switzerland, Phone +41 31 9604330, Fax -31; marc.wenger@b-i-g.ch

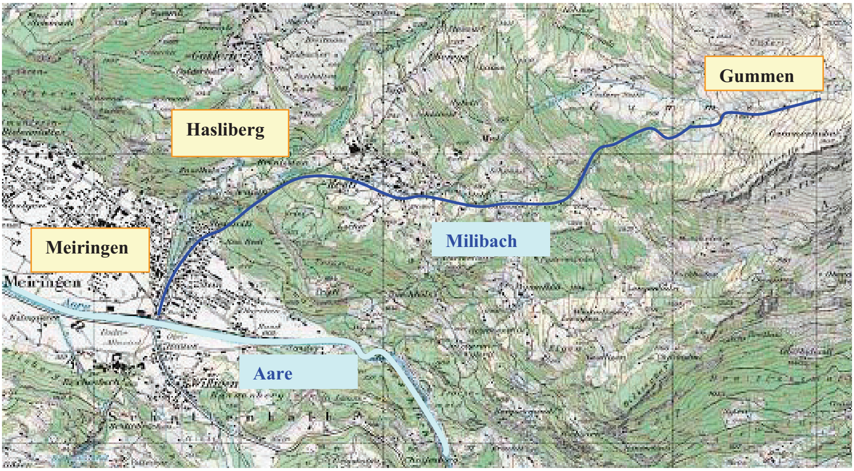

Fig 1: Situation of the Milibach River, from *Landeskarte der Schweiz (Bundesamt für Topographie)*, Number 1209 Innertkirchen (1:25'000).

GEOLOGICAL ASPECTS

The Gummen valley is comprised of beds of slope-parallel black clay-rich Alénien schist (Alénienschiefer in German) occasionally interbedded with sandstone beds. The schist is very sensitive to weather conditions and acts as an aquiclude (Wenger, 2006).

The bedrock is covered by a several meter thick layer of weathered debris. This layer is the source sediment for debris flows. Moraine deposits are rare in the source area.

Fig 2: Catchment area with the Milibach River in the Gummen region (left), Alénien schist material (right).

The debris consists of poorly sorted sediment with grain sizes spanning the range from abundant clay, silt, sand, but also many cobbles and even large boulders. The dry internal friction angle φ' lies between 25-28° with an apparently cohesion of c' = 0-3 kN/m^2. When saturated, these values decrease, for example the internal friction angle decreases to 15°. The low plasticity of the material is striking. The fraction of clay and silt counts 15-20 %, presenting a significant problem for the retention constructions because they have to be kept very flat by the use of retaining walls. After wet periods following long-duration and intensive rainfall, the material is mobilized as hill-slope debris flows which transport the debris into the river channel.

EVENT 2005

In August 2005 during heavy rainfall the settlements of Hasliberg, Reuti and Meiringen were flooded. The debris flows from the Gummen region were mainly responsible for the disaster (Bezzola & Hegg, 2007).

Around 13.000 m^3 of the weathered schist material in the catchment were mobilized during the intensive rainfall and were transported in 3 waves down the channel. An additional 25.000 m^3 were entrained along the flow path, increasing the total volume of the flow to around 40.000 m^3. The cadastral event register notes events like 2005 occurred often the last centuries.

The flow velocities of these events were estimated at approximately from 7 up to 9 m/s by using super-elevation of the deposits. The velocities, flow heights and flow discharges can be estimated assuming a turbulent Newton flow regime using a Chezy or Strickler approach (Zimmermann, 2005).

The shear stresses at the margins of the flow were approximated from border deposition after the events to 600 / 1100 N/m^2. Hence, these debris flows were muddy flows. The water content of the flows is estimated at about 50 %. The density of the flow itself was in the range of 1800 - 2000 kg/m^3.

DEBRIS FLOW DESIGN DATA

Table 1 summarizes the engineering design values for the protection concept (Herzog Ingenieure, 2006).

Tab 1: Debris flow design values.

Parameter	Design value	Overload case
Channel inclination	30 %	-
Type of debris flow	Mud flow, viscous flow	-
Total volume	10.000 - 15.000 m^3	-
Surge volume	5.000 m^3	-
Flow bulk density	18 - 20 kN/m^3	18 - 22 kN/m^3
Max. discharge	60 m^3/s	100 - 150 m^3/s
Flow height	1.5 - 2 m	-
Flow velocity	6 - 12 m/s	up to 18 m/s

TODAYS STATE OF DEVELOPMENT OF RINGNET BARRIERS

It has been demonstrated in many projects from Europe, Asia, and the USA that flexible ring net barriers as used in rockfall protection systems are well suitable to stop debris flows. To study the interaction between debris flows and flexible ring nets more closely, full field- scale tests in the Illgraben Valley (Canton Valais/Switzerland) have been carried out starting in 2005 (Wendeler et al., 2006).

Fig 3: Full scale field test site for ring-net barriers at the Illgraben, Switzerland: Barrier empty (left) and filled (right). On 18.05.2006, 15.000 m^3 debris material flowed through and over the barrier. A volume of 1.000 m^3 was retained, while the rest overflowed the barrier without damaging it.

Further research since 2006 at the site Merdenson, also in Switzerland, with three nets installed in-series indicates that the *multi-level approach* is suitable for retaining larger volumes of debris flow material. Furthermore, the goal of the Merdenson project is to study the energy absorption resulting from the step effect of such a staggered multilevel barrier, and the long term performance of the filled barriers in the stream.

Fig 4: Multilevel Barrier Merdenson, Switzerland: 3 barriers in series empty (left) and filled (right).

The field experience at the Merdenson River during the last two years provided the following results:

- Flexible debris flow barriers constructed using ring nets may be used to successfully stop or reduce the volume of a debris flow without being damaged.
- Overall, 1.000 m^3 of material was retained behind the barrier, up to 50.000 m^3 material overflowed the barrier during one event. Each year, the barrier was overtopped by an estimated volume of more than 200.000 m^3 during the observation time (6 months, 7 – 8 debris flows per year).
- The wing-shaped arrangement of the upper support ropes, which create a clearly-defined flow section in the middle of the barrier, and the abrasion protection devices on the upper support ropes appear to be a successful design.
- Overtopping of the barriers by debris flows and sediment transport is possible, supporting the design concept that a series of barriers may be used to stop volumes of debris larger than are possible using only one barrier.

LABORATORY TESTS AT THE WSL

A series of 7 laboratory experiments were run to quantify the influence of different mesh sizes and the aperture between the lowest support rope and the river bed compared to the maximum grain size. To simulate the real behavior of the flow natural debris flow material taken from the local river bed was used. Because of the limited width of the laboratory channel, only the material smaller than 3 cm was used, alternatively, 90 % by volume of the material for the experiments was smaller than 3 cm. A comparison of the laboratory barrier with the real sized barrier system can be seen in Figure 4.

Fig 5: Mesh size and basal opening in the laboratory (left) and in full scale (right).

The experimental results indicate that it is possible to study the filling process and the retaining behavior of the barriers as a function of the mesh size. Reasonable results were obtained with the net having a mesh size and opening approximately equal to the size of d_{90}, i.e. the sediment size where 90 % of the sediment (by volume or mass) has a smaller grain size. Scaling the laboratory tests to prototype scale using Froude similarity indicates that the barriers should have a ring diameter between 0.3-0.5 m to achieve a reliable retaining performance. The basal opening between the lower support rope and the river bed should also be of the same dimension (Wendeler, 2006). These conclusions are also based on numerous preceding laboratory tests using different debris material, e.g. from the Illgraben river.

DIMENSIONING OF 13 FLEXIBLE RING NET

The dimensioning of the flexible ring net barriers was carried out using the finite element software package FARO (Volkwein, 2005). FARO was developed for analyzing the internal force distribution within ring-net barrier systems and as an overall evaluation and design tool for the dimensioning of such barriers. Using data from the Illgraben test site, the model has been modified for debris flows and been successfully applied for debris flows (Wendeler et al., 2006). Debris flows produce aerially-distributed loads instead of small-area or point loads as in the rockfall case. Additionally, in comparison with rockfall, debris flows are characterized by longer duration impact, smaller deflection, and they typically occur in several discrete surges.

For the dimensioning of the 13 nets at Gummen, Hasliberg, the following load cases are considered:

- Granular debris flow;
- Muddy debris flow;
- Static load (active earth thrust);
- Snow (gliding and impact of a small avalanche);
- Overtopping by subsequent debris;

Barrier number 1 (the uppermost barrier) was dimensioned as a so called "debris flow breaker" and the highest intensity level of debris flows was simulated. In case of infilling, the retention capacity of this barrier is lost but at least part of the energy at the debris flow front will be absorbed.

Barrier number 2 is additionally dimensioned to absorb the energy of a snow avalanche impinging at an angle of 10° from the line parallel with the net. Furthermore, calculations indicate that the forces in the cables remain below the activation threshold of the brake elements and therefore they do not have to be specially secured in winter time.

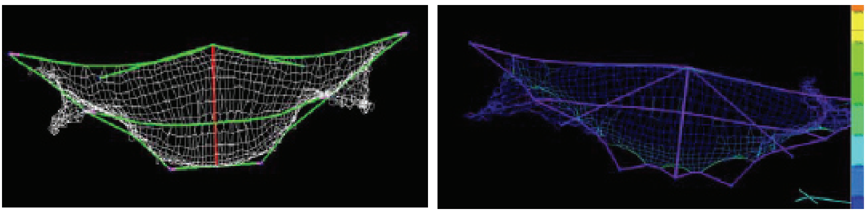

Fig1: Simulation of representative barrier for project Gummen using the software FARO.

The calculations indicate that for the given requirements, only the very strongest nets should to be used for this project. Therefore, the components used for the ring net, the ropes and the brake rings are the strongest elements available.

CONCLUSION AND OUTLOOK

Flexible ring-net barriers are multi-functional mitigation devices commonly applied to rockfall or floating-wood protection in floods, snow avalanches, and also for mudflows or granular debris flows, if properly dimensioned for the process or processes for which they are intended. Advantages include lightness and therefore quick and easy installation with a properly-dimensioned rope anchor system. Ring diameters should be dimensioned to be approximately equal to the size of the d_{90} of the grain size distribution, as indicated by laboratory tests, to produce a reliable retaining behaviour, even for mud flows.

All the tests done with the nets in Illgraben and Merdenson river demonstrate that these barriers can be used for retaining small debris flow volumes, and in series they have a larger retention capacity.

The long-term-behaviour of the barriers is only known from the rockfall protection which is generally not subjected to the effects of continuously flowing water. But for applications where the filling process will occur infrequently, the barrier can remain suspended above the river bed, preferably in a place where the bed is not subjected to progressive scour, where it will only be activated by flows exceeding a certain design flow depth. If so designed, the long-term behaviour corresponds to rockfall barriers. As with any preventative structure, regular inspection is necessary.

The installation of this series of 13 barriers in Oberhasli is the first design of such a protection system in Switzerland. All companies and authorities involved in the project worked closely together to improve the protection of the Hasliberg region using a completely new protection measure for a safe future with less probable debris flow damages

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