Ten Years' Experience in Flexible Debris Flow Barriers

Corinna WENDELER[1*], Nobuhito NISHIMRUA[2]
and Matthias DENK[3]

[1] Geobrugg AG (Romanshorn, Switzerland)
[2] Geobrugg Japan K. K., Japan
[3] EMDES Environmental Engineering, Switzerland
*Corresponding author e-mail: corinna.wendeler@geobrugg.com

More than 20 flexible ring net barriers for debris flow protection were installed in the last 20 years, in over 25 countries and have been protecting infrastructure, roads and railway tracks from great damage. These flexible ring net debris flow barriers have been in the meantime established as a certified European product, obtaining the CE marking. This contribution relates the evolution of the first real scale testing barriers, leading to standardized barriers up to fully working debris flow barrier projects. Case studies will highlight advantages and challenges of this technology in regards to construction technics, economical aspects and its environmental friendly characteristics.

Key words: debris flow, flexible protection, ring net, CE-marking

1. INTRODUCTION

Since 2005, over 250 flexible debris flow barriers have been installed, in more than 25 countries. Between 2005 and 2008, full scale experiments at the test site Illgraben, in Switzerland, proved the feasibility of retaining debris flows.

The efficiency of some of the first reference projects, mostly installed in Switzerland, was analysed and a load design was then established together with the Forest, Snow and Landscape Federal Institute (WSL). Standard systems were then developed with the simulation software FARO. Data from real-scale testing were used to verify and calibrate the software outputs.

Following this development, the flexible ring nets became increasingly an alternative to classical debris flow barriers in Europe, USA and South America. In large scale projects, where flexible nets were installed in a row in the same channel, the efficiency of retaining large volumes and the feasibility of this type of installation in a row were proven as well.

Flexible nets are appreciated, by designers and engineers, as a practical and economical addition or alternative to existing classical debris flow protections.

Ten years of experience with flexible ring net barriers signify that their advantages have been recognised and their efficiency in the field have been established. The increasing knowledge of single barriers, barriers in a row and large scale barriers have allowed to understand the advantages but also the limits of such a flexible debris flow barrier. This acquired knowledge is presented in the following paper, accompanied by case studies.

2. REAL-SCALE TESTING IN ILLGRABEN, DEVELOPMENT OF STANDARDIZED FLEXIBLE DEBRIS FLOW BARRIERS AND CE MARKING

2.1 Real-scale testing in Illgraben

Between 2005 and 2008, real-scale testing was conducted in the Illgraben debris flow channel, in Wallis, in Switzerland (Wendeler, 2008). Prior testing it was observed that rockfall protection nets were retaining some slides but the dimensioning concept was missing to prove that flexible ring nets could retain larger debris flows in a channel without sustaining damage. In Illgraben, a middle to large debris flow is occurring at least once a year naturally and therefore a flexible ring net could be tested yearly (see **Figure 1**).

Two key characteristics were defined and analysed with testing. On one hand, a single barrier could, depending on the channel geometry, retain over 1000 m^3. On the other hand, it was observed that over 10’000 m^3 were flowing over the barrier without damage. This led to planning and constructing a debris flow retention system with several flexible nets in a row in order to retain successfully most of the material.

Figure 1: Testing of debris flow retention system with ring net in the Illgraben channel, 2006. Retention volume approx. 1000 m^3

On the dimensioning side, the weight acting on a debris flow barrier during an event were better understood, thanks to an extensive measuring concept on and around the system (Wendeler, 2006), which lead to the final dimensioning concept (Wendeler, 2008).

2.2 Development of standardized barriers

The dimensioning concept as well as the distribution of the loading on the flexible net were integrated in the finite element software FARO (Volkwein, 2004) and first projects, mostly in Switzerland, were dimensioned with it.

Following the first projects, flexible standardized debris flow barriers were designed with a given load capacity in kN/m^2. VX-barriers are conceived for channels up to 15m in width und barrier height of up to 6m, taking loads up to 160 kN/m^2. UX-barriers find their application in larger channels, are installed with additional posts, a barrier height up to 6m and taking up loads of 180 kN/m^2 (Geobrugg, 2016) (see **Figure 2**).

The dimensioning concept for debris flows is now state of the art and freely accessible through the software DEBFLOW on Geobrugg’s website[1]. After registration on the website, everybody can use this software and produce a first estimate for the dimensioning of a barrier.

Figure 2: UX debris flow barrier, with posts for wider stream channels application. Example of the Trachtbach in Switzerland. Additional scour protection, rip-rap and lean concrete were placed along the stream bed.

2.3 CE marking

The real scale testing was also basis for certifying all flexible standardized debris flow barriers. Certification was achieved in 2017 (EAD document Nr. 340020-00-106[2]). The CE marking is based on a “European Assessment Document” which defines precisely the suitability, the type classification and yearly quality controls necessary to correspond to a certain standard. This states that the products with CE marking fulfil the European guidelines for product quality and field appropriateness and allows an unrestricted trade within the European Union (ETA 17/0268-17/0276 and ETA 17/0439).

3. DIMENSIONING

An easy predetermination of the dimensioning of a flexible standardized debris flow barrier up to 6 m in height can easily be performed with DEBFLOW. A more complicated scenario can still be dimensioned by Geobrugg or WSL with FARO simulation software. A few special cases in regards to construction are described in the section 6.

3.1 Special load case scenario such as snowslides and rockfall

In certain cases, mostly very steep slopes (>35°) and at high altitude, snow slides, small avalanches or rockfall will be encountered, which could or will impact the debris flow barriers.

An example of this situation is the multiple barrier setup in Hasliberg in Switzerland. Some of the barriers are situated above 2000m in elevation. Since flexible net barriers are also used as a protection against avalanches and rockfall, a certain degree of combined loading can be guaranteed. The combined loading can be calculated and a barrier dimensioned for every special case with the use of FARO simulation software (Volkwein, 2004). Specific components of the debris flow barrier can be individually reinforced depending on the simulation results (Wendeler, 2014).

Figure 3 illustrates the simulated load case for barrier number 2 in Hasliberg in a situation of a lateral avalanche impact, with an angle of 10° and a load of 120 kN/m^2. In this special case, the upslope guy wires are loaded up to 70% of their capacity. **Figure 4** shows snow load on the barrier in winter.

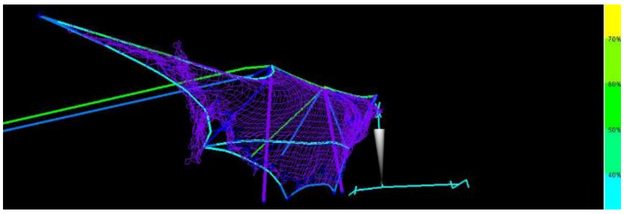

Figure 3: FARO simulation software output when barrier number 2 is impacted by an avalanche in Hasliberg, Switzerland.

Figure 4: Same net than in figure 3, partially snowed in during winter. The snow load has to be taken into account when designing the barrier.

4. CONSTRUCTION ASPECTS

4.1 Subsurface and anchoring

While the netting itself is easy to model and to dimension, safe anchoring is more complicated.

Ideally, a detailed geological profile of the section to be protected is available as well as the geotechnical parameters of the subsurface. Having the possibility to perform pulling tests on the soil nails to assess the friction between the subsurface and the grout is another advantage.

Debris flow deposits are heterogeneous in nature and deposited along the sides of the channel affecting the subsurface quality for anchoring. The dimensioning of anchor forces need to be determined by experts in those cases. It is as well recommended to use self-drilling anchors with a flexible anchor head. The barrier when loaded is largely deformed and the forces of the ropes on the anchors can change up to 30° in angle. This eccentricity without flexible anchor head is often not bearable for a normal threaded anchor since the pushing resistance is much smaller than the pulling component.

4.2 Reuse of the anchoring after a debris flow event

Without additional flank stabilisation, a certain degree of washing out can be observed along these stream banks, especially in loose soil (see **figure 5**).

When exchanging the net, the anchoring can technically be reused when the top of the anchor is cut off, a loading test is performed and a new flexible anchor head is mounted. Assuming that the anchor length was drilled the first time with a safety factor and possesses a certain length in reserve. In the case of frequent filling of the net it is recommend to design the anchors with sufficient length or to prevent the washing out of the banks with structural countermeasures.

Figure 5: Washed out anchoring of the debris flow barrier number 25 in the Illgraben channel. Anchoring partially in loose material and partially in disused concrete debris flow barrier.

4.3 Structural countermeasures: protection of the banks in stream bends

Especially in bends along the stream, the washing out of the outer bank and its erosion are prevalent when a debris flow occurs. The amount of erosion is dictated by the volume and the velocity of the flow. Depending on the project a reinforcement of the outer bank should be considered (rock blocks, wall, gabions or additional flank stabilization by netting with or without erosion control mats (see **Figure 6**)).

It is important to consider that the shearing forces of a debris flow are much higher than of water and this has to be incorporated in the design calculation for the protection measures.

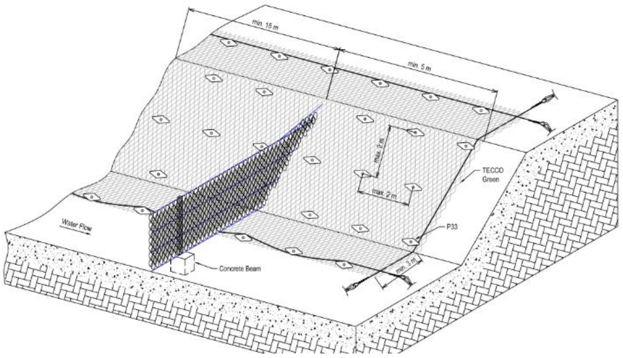

Figure 6: Slope stabilisation with TECCO for flank stabilisation when installing a debris flow barrier in loose material.

4.4 Scour protection

Scouring occurs around construction base or posts due to sediment erosion and leads to scour holes which directly affects the construction stabilisation. When barriers are filled or partially filled, the stream flow passes at its lowest level. Optimally the lowest level is at the cross-section centre of the flexible net system and the flow path stays within the original stream bed. Since the optimal case does not always exist, stream flow path passes lateral at the flank side and erodes material around the construction base or posts. This is especially important for barriers retaining a debris flow in an open field rather than in the stream bed itself. To avoid scouring, flank stabilisation with a rock wall became established and anchored rock blocks as well as rip-rap and lean concrete along the stream bed (**Figure 2**). Further, it has to be considered whether a field needs an artificial channel back to the original stream underneath the flexible net system, in case of lateral stream flow paths.. When choosing rock walls as solution flexible net system dimensioning further downstream should take into account the possibility of these rock blocks getting torn away. The additional load being potentially fatal to the barrier.

5. PLANNING ASPECTS

Often debris flow barriers are installed close to the source zone of the debris flows while greater structural measures such as a retaining basin or deviation measures are constructed further down.

Flexible net barriers and large steel and concrete construction can therefore be perfectly combined. The advantages of both methods can be specifically used together. An example of this combination are the streams Trachtbach in Brienz and Milibach in Hasliberg, both located in Switzerland. In both projects, the combination of the nets upstream and the larger construction measures downstream allowed to increase the retained mass upstream and diminish erosion in the stream bed.

Therefore the capacity of the concrete protection measures could be lowered and constructed at smaller scale and existing protection structures were easily and cost effectively renovated and added to the protection measures series.

5.1 Flexible net barriers as an immediate solution

Flexible net barriers installed in the source zones of debris flows, slow these down, which allows for longer warning and evacuation time in the endangered areas. This is especially of importance in small catchment zones where debris flows are rapid and travel along short distances only.

The easily installed flexible net barriers are therefore practical for an immediate protection solution. They increase the safety of the infrastructure downstream and even allow for the protection of the construction crew building a retaining basin for example. These protection nets can be equipped as well with a warning system (more details are given in section 7).

5.2 Visual and landscape protection aspects

Debris flow barriers instead of concrete dams are more and more an alternative in regards to landscape protection and visual aesthetics. The filigree design is almost invisible from far away and a primary argument for protection measure construction in landscape protection zones.

An example is the Unesco World Cultural Heritage along the Rhine close to Koblenz (**Figure 7**). At the back of the village debris flow barriers are installed and even with one barrier partially filled in 2017, the nets are still barely visible but fulfilling their purpose (**Figure 8**).

Figure 7: Almost invisible debris flow barrier close to Koblenz along the Rhine above an Unesco World Culture Heritage protected village.

Additionally, environment friendly building and sustainability is more and more an important argument for construction. For example, a debris flow barrier (ten by 4 meters) is 30 times lighter than a concrete barrier of the same dimensions, making it the 'greener solution'. On top of that with less weight, less carbon dioxide is emitted during transport to site (Wendeler, 2008).

Figure 8: Partially filled debris flow barrier above the German Railway close to Koblenz.

5.3 Passage for small animals and greening

The relatively large openings of the ring nets allow for passage of small animals, when the barrier is not filled, even fishes when the barrier is immersed in water, in contrast to a concrete structure (Wendeler, 2008). There are examples where this was an expressed wish of the developer. Ring nets are as well appropriate for greening and blend perfectly into the landscape.

6. DIFFERENT TYPES OF DEBRIS FLOW BARRIERS

6.1 Single barriers

Figure 9: Debris flow barrier in Isenflue above a settlement. The outer bank of the stream was reinforced with a rock wall.

Most barriers installed are single barriers along roads and railway tracks or above settlements (see **Figure 9**).

6.2 Barriers in a row (multi-level barriers)

Debris flow nets can be installed in a row, to increase the retained volume. The first mutli-level barriers were installed in Merdenson in Switzerland for observational purposes by the WSL (Denk et al., 2008).

Subsequent laboratory tests to analyse the overflow behaviour, and more specifically the overflow velocity evolution during a flow, confirmed the developed load design for multi-level barriers (Wendeler et al., 2010).

Examples for this setup are the multi-level barriers in Hasliberg (Wendeler et al., 2014) in Switzerland but also in Portainé in Spain (Luis et al., 2010) as well as Ana Chosica in Peru.

Most of the multi-level barriers have already been successfully filled during events (see **Figure 10**). Chosica is the most recent example in 2017, protecting efficiently several cities built downstream (see **Figure 11**).

Figure 10: 11 debris flow protection barriers, successfully filled in Hasliberg in 2011.

Figure 11: Filled debris flow barrier in 2017 in Peru, protecting successfully a large city downstream.

6.3 Large debris flow retention with single barrier (special construction)

In special cases an adapted design higher than 10m and larger than 40m can be constructed. A typical example is the debris flow barrier in Hüpach, next to Oberwil in the canton Berne in Switzerland (Berger et al., 2016).

This barrier has a retaining capacity of more than 12’000 m^3. Such a construction necessitates strong abutments of steel reinforced concrete, long anchors and needs special ropes used for cable cars which need precise adjustment (see **Figure 12**). Special calculations for the netting and the ropes, adjustment to the anchoring and special foundation engineering in exposed terrain was necessary to complete the project. The decision to install a large retaining structure with netting was based on the topography, the difficulty of access and lack of alternatives to protect the village below. The debris flow barrier has not been filled yet.

Another special construction is situated in Sitäbach along the stream Lenk, in Switzerland. The construction is based on concrete slices and netting in between (see **Figure 13**).

Figure 12: Special construction of a debris flow barrier in Hüpach, in Switzerland, with a width of 40m and a netting height of 10m.

Figure 13: Another special construction acting as a debris flow barrier in Sitäbach consisting of concrete slices piled up and netting mounted in between.

7. SURVEILLANCE

Flexible debris flow barriers can be monitored with sensors (Sentinel System). In larger systems, some components can be monitored such as the ring brakes and when a loading threshold is reached, an alarm is triggered.

An example is the debris flow barrier, installed as an immediate protection solution, in Magnacun in Switzerland. The railway tracks of the Rhaetian Railway are perfectly protected since 2009, with the surveillance system working faultlessly, according to the developer.

8. MAINTENANCE AND CLEANING OF BARRIERS

As any protection structure, debris flow barriers require maintenance from time to time. It is recommended to undertake regular, for example yearly, checks of the protection system if no event (debris flow, slides, …) occurred during that time span. Working with a checklist and a maintenance scheme, such as for any other protection structures, should facilitate regular controls.

After an event, the barrier needs emptying and replacement of certain components. A filled barrier can for example be cleaned from behind with an excavator. It is essential, when planning for the system, to consider what happens to the material of the debris flow and to organise a deposit area. Budget wise, it has to be considered that after a fully filled barrier, parts have to be replaced, whereas the anchoring can often be reused, as explained earlier.

A net can be emptied from the front when certain conditions are fulfilled. The material of the debris flow has to be dry and stable and the netting has to be stabilized upslope and safety aspects for the working crew have to be respected.

9. ADVANTAGES AND LIMITS OF FLEXIBLE NETTING FOR DEBRIS FLOW PROTECTION

The main advantages of these systems is their relative low weight and rapid installation. Especially in steep and in terrain difficult of access. The material can be transported with helicopters wherever construction machines cannot reach the site or where it would not be economical.

Ring nets can be used for immediate protection in endangered zones to safeguard the construction of a permanent structure below. These practices are common for example in Japan. Ring nets can therefore be incorporated in an overall protection concept for an entire catchment area.

At the same time it has been proven over time that ring net barriers are fully equivalent to large concrete structures when properly planned, with an erosion control concept and an established maintenance plan.

Obviously in easy access areas with high frequency of debris flows, permanent concrete structures are to be favoured as they are more economical in such a particular case.

10. CONCLUSIONS

Since the publication of the load design of flexible debris flow barriers and their appropriateness tests in the Illgraben in Switzerland, many projects have been successfully installed in the last 10 years.

Several construction details have been revised and improved. When taking into account the hydrological processes affecting the stability of the stream banks and planning for reinforcement, the flexible ring net systems can be considered as equivalent to classical large concrete protection structures. To prevent steel corrosion the used flexible net system has a zinc- aluminum coating. For more restrictive corrosion conditions, other solutions such as stainless steel or a thicker coating layers are options for longer lifetime guarantee. Therefore no material disadvantage is evident compared to concrete barriers. Further, the lighter conception of the barriers make it an unavoidable solution when easy handling, environmental requirements and landscape protection are key issues of a project.

The dimensioning concept developed at the WSL, in use worldwide, has been verified by several filling and successfully retaining events. A further adaptation and refining of the dimensioning concept could be achieved with more testing, but is hampered by lack of funding.

REFERENCES

Berger C., C. Wendeler, L. Stieglitz and G. Lauber (2016): Examples of debris retention basins combining concrete and net structures, Interpraevent Luzern, Switzerland.

Denk M., A. Roth, C. Wendeler und A. Volkwein (2008): 1:1 Feldversuche für flexible Schutznetze gegen Murgang – Versuche, Bemessung, Anwendung, Publikation für die Technische Akademie Esslingen, Deutschland.

Geobrugg (2016): Ringnetzbarrieren aus hochfestem Stahldraht: Die ökonomische Lösung gegen Murgänge, Schweiz.

Luis-Fonseca R.., C. Raimat, J. Albalate and J. Fernandez (2010): Protecion contra Corrientes de derrubios en areas del Pirineo. Obras Urbanas, Julio/Agosto 2010 numero 22, Spain.

Speerli J., R. Hersperger, A. Roth and C. Wendeler (2010): Physical modeling of debris flow over flexible ring net barriers, Conference on Physical Modelings in Geotechnics ETHZ, Switzerland.

Volkwein A. (2004): Numerische Simulation von flexiblen Steinschlagschutzsystemen, Dissertation ETHZ, Schweiz.

Wendeler C., B.W. McArdell, D. Rickenmann, A. Volkwein, A. Roth and M. Denk (2006): Testing and numerical modeling of flexible debrs flow barriers. In Zhang, M. and H. Wang (eds.): Proc. Of the sixth International Conference on Physical Modeling in Geotechnics, pp. 1573-1578. Balkema.

Wendeler C. (2008): Murgangrückhalt in Wildbächen – Grundlagen zu Planung und Berechnung von flexiblen Barrieren, Dissertation ETHZ, Schweiz.

Wendeler C., J. Glover (2014): Multiple load case on flexible shallow landslide barriers – mudslide and rockfall, IAEG Conference Turin, Italy.

Wendeler C., A. Volkwein, A. Roth and N. Nishimura (2014): Successful hazard prevention using flexible multi-level barriers, Interpraevent in Nara, Japan.

[1]:https://www.geobrugg.com/en/Welcome-to-myGeobrugg-79860.htmlintegriert)

[2]:http://eur-lex.europa.eu/legal-content/DE/TXT/PDF/?uri=CELEX:52017XC1013(01)