# DEBRIS FLOWS: Disasters, Risk, Forecast, Protection

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# СЕЛЕВЫЕ ПОТОКИ: катастрофы, риск, прогноз, защита

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# კატასტროფები, რისკი, პროგნოზი, დაცვა

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თბილისი, საქართველო, 1–5 ოქტომბერი, 2018

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# Multi-level flexible debris flow barriers: case study in Peru

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Geobrugg possesses over 10 years' experience in developing, dimensioning and installing flexible ring net barriers against debris flows. Flexible ring net system have proven to be an equivalent to classic large concrete protection measures. At same safety level they have many advantages in terms of fast and easy installation, environmental impact as well as landscape protection considerations. A back analysis of the efficiency of some of the first reference projects was made. This presented the basis for a load design developed together with the Swiss Federal Institute of Forest, Snow and Landscape (WSL). Simulations calibrated and verified in 1:1 field tests have been used to develop standard systems for different load cases. These systems have been tested and certified for CE-Marking in 1:1 field tests. Debris flow barriers can be installed as a single barrier or in a row, to increase total retention volume. This contribution relates the dimensioning and installation of a multi-level debris flow barrier in Peru and its successful retention of a large event, protecting efficiently the urban area of Chosica. The project consisted of 22 barriers installed in 9 valleys, in the winter months of 2016. The barriers were dimensioned with the software DEBFLOW1. A year later, large debris flows occurred and we will focus on two barriers which retained approximately 10'000 $m^3$ of material and were filled to 95%. The barriers downstream presented enough retention capacity to cope with a potential following event. Maintenance was undertaken in January 2018, and the barriers are fully functional for the next debris flow season.

*debris flow mitigation, flexible ring-nets, Peru*

# Многоуровневые гибкие противоселевые барьеры на примере работ в Перу

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Geobrugg обладает более чем 10-летним опытом разработки, определения размеров и установки гибких кольцевых сетчатых барьеров для защиты от селевых потоков. Гибкая система кольцевых сетей оказалась эквивалентной классическим крупным мерам защиты из бетона. На том же уровне безопасности они имеют много преимуществ в плане быстрой и простой установки, воздействия на окружающую среду, а также из соображений сохранения ландшафтной среды. Был сделан обратный анализ эффективности некоторых из первых эталонных проектов. Это послужило основой для разработки системы, созданной совместно со Швейцарским федеральным институтом леса, снега и ландшафта (WSL). Моделирование, калиброванное и проверенное в полевых испытаниях в натуральном размере, использовалось для разработки стандартных систем для различных нагрузок. Эти системы были протестированы и сертифицированы для маркировки CE в полевых испытаниях в масштабе 1:1. Барьеры для защиты от селей могут быть установлены поодиночке или каскадом, чтобы увеличить общий объем аккумуляции материала. В данной публикации рассматриваются измерение и установка многоуровневых селезащитных барьеров в Перу и их успешная роль в задерждании селевого материала в период большого события. Барьеры эффективно защитили часть города Чосика. Проект состоял из 22 барьеров, установленных в 9 долинах в зимние месяцы

2016 года. Барьеры были рассчитаны на программное обеспечение DEBFLOW1. Через год произошли большие селевые потоки. Рассматриваются два барьера, которые сохранили приблизительно 10 000 м$^3$ материала и были заполнены до 95%. Барьеры, расположенные ниже по течению, обеспечивают достаточную способность удерживать материал, чтобы справиться с потенциальным последующим событием. Техническое обслуживание было проведено в январе 2018 года, и барьеры полностью функциональны для следующего селеопасного сезона.

*Защита от селей, гибкие кольцевые сети, Перу*

## Introduction

The effect of "El Nino" combined with regular precipitation during the rainy season, from January to end of April, leads to recurring debris flow disasters, in Peru. Debris flows occasion great damage to infrastructure and endanger lives and livestock. In 2015 alone, eight people lost their lives in a debris flow event and led to infrastructure loss and destruction costs of over 58 million USD. Other examples are the debris flows, in 1987, coming from the San Antonio de Pedregal stream, which killed 100 people. Eleven years later, 320 got injured, two died and 200 houses were destroyed.

To prevent vulnerable areas from being affected by further debris flow disasters, different type of mitigation measures can be installed. The municipality of Chosica, in the Lugarincho-Chosica district of the province of Lima, is particularly affected by debris flow due to its geographic location. Enclosed by steep valleys incised by torrents, the municipality opted in 2016 for 22 flexible ring net barriers, distributed in nine of these surrounding valleys, installed during winter 2016. The used flexible ring net barriers are standardized flexible debris flow barriers from Geobrugg. The barriers' dimensions were determined by the dimensioning tool DEBFLOW1, freely accessible on Geobrugg's website.

A year after completing the flexible ring net barriers, large debris flows occurred again and the barriers successfully retained the debris material. As an example, two barriers retained approximately 10'000 m3 debris material and were filled up to 95%. Further downstream, additional barriers, installed as a multi-level system, presented enough retention capacity for a potential following event. This paper presents acquired knowledge of Geobrugg's 10 years' experience in developing, dimensioning and installing flexible ring net barriers against debris flows through the example of the mentioned case study in Peru. Another example of Geobrugg's experience, particularly in the multi-level installation, is an example in the Spanish Pyrenees, in Port-Ainé. Nine VX-barriers were installed in 2009, combined with extensive monitoring of the catchment basin and were successfully filled in a large debris flow event in Summer 2010, with a total volume of approx. 25'000 m3 (Luis-Fonseca et al., 2010).

## Method

*Debris flow standardization and created systems*

While using flexible ring nets for rockfall protection it was observed that some slides got retained. However, no dimensioning concept existed proving that flexible ring net barriers can retain large debris flows. Therefore, real-scale experiments with flexible ring nets were performed at Illgraben test site in Switzerland between 2005 and 2008 [*Wendeler, 2008*]. At least once a year, a middle to large debris flow naturally occurs at Illgraben which proved to be an ideal test site location. The tests showed that a single barrier can retain 1000 m$^3$ depending on the channel geometry (see Fig. 1) and that over 10'000 m$^3$ of material can overflow the barrier without damage (Fig. 2). Thus, a debris flow retention system with several flexible ring nets in a row, so-called multi-level system, can be planned and constructed. Another test site in Switzerland, in Merdenson, confirmed this theory and allowed the extension of the dimensioning concept to multi-level systems (see Fig. 2). An extensive measuring concept on and around the system led to the final dimensioning concept [*Wendeler, 2008*]. Based on the field test data, the flexible ring net dimensioning concept, the loading distributions, and simulations with the finite element software FARO [*Volkwein, 2004*] led to the development of standardized flexible ring net barriers. These barriers are defined according to the load their surface can cope with, in kN/m$^2$, as well as the system height.

Two types of standardized barriers were designed: VX-barrier and UX-barrier (Fig. 3). The VX barrier takes loads up to 160 kN/m$^2$ and is used for narrow channels (V-shaped valleys), with a width up to 15m, and a barrier height of up to 6m. UX-barrier are used for larger channels (U-shaped valleys), with additional posts as required, with expected loads up to 180 kN/m$^2$ and a barrier height up to 6m [*Geobrugg, 2016*].

(a) (b)

Fig. 1. Testing of debris flow retention system with ring net in the Illgraben channel, 2006. Retention volume approx. 1000 m$^3$. (a): barrier after installation, (b): filled barrier after debris flow event

(a) (b)

Fig. 2. (a): flexible ring net barrier withstanding overflow in the Illgraben; (b): 1:1 field testing of multi-level barriers in Merdenson, Valais, Switzerland

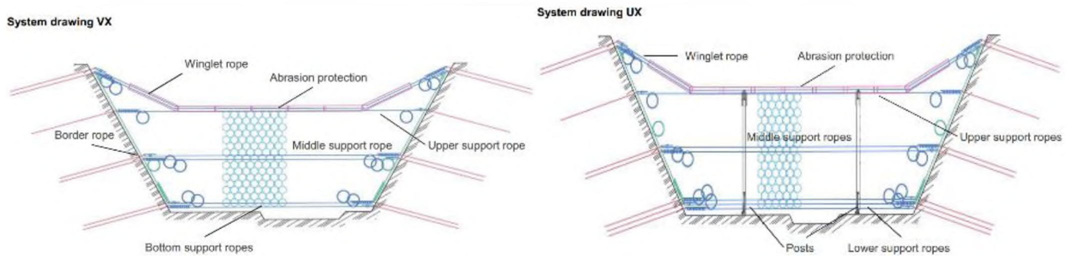


Fig. 3. Schematic diagram of standardized VX-barrier and UX-barrier. The main components are the flexible ring net, top, middle and bottom support ropes with corresponding ring brakes, abrasion protection, winglet components, anchoring and posts for the UX-barrier

*CE marking*

Flexible standardized debris flow barriers certification was achieved in 2017 (EAD document Nr. 340020-00-1062). The real-scale testing served for certifying the flexible standardized debris flow barriers. 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. For further information please see: https://ec.europa.eu/growth/single-market/ce-marking_de. There are two main benefits CE marking brings to businesses and consumers within the European Economic Area (EEA). Firstly, businesses know that products bearing CE marking can be traded in the EEA without restrictions. Secondly, consumers enjoy the same level of health, safety, and environmental protection throughout the entire EEA. Concerning debris flow barriers, CE marking guarantees for user and client a declared performance of the net systems according to EAD Document NO 340020-00-106. The performance is declared in kN/m$^2$ impact pressure of first debris impact.

## Case Study Peru

*Background and fieldwork*

Peru is located in the western part of South America adjoining the Pacific and the Andes mountain range. Due to the tropical location and the large altitude range, Peru has drastically varying climatic conditions and weather phenomena such as El Niño.

Between 2003 and 2015, according to Peru’s national civil defence, 4484 flood events and 1388 debris flows occurred affecting directly population, crop areas, road and productive infrastructure [*ANA, 2017*]. However, not all of these events are related to solely the El Niño phenomenon, short and intense precipitation combined with the presence of loose material simply leads to debris flows, with severe consequences in urbanized areas.

Since these recurring events have been recognized, several studies were realized in the last 30 years such as geological and geomorphological studies, geological hazard risk analysis, and evaluation and consequences of debris flows. Based on the knowledge obtained from these studies, the importance of mitigation measures was recognized in Peru. As already mentioned, the municipality of Chosica, was hit several times by severe debris flow events. The particular geographical setting leads to this vulnerability, Chosica being surrounded by steep dewatering slopes, covered by unconsolidated material, product of the cordillera’s erosion (Fig. 4). These slopes present each a sufficient large catchment area with one main dewatering direction, i.e towards the valley, where the urban area is settled. A comprehensive field analysis was conducted to stake out the barriers’ best locations and to estimate the volume of potential flows. Finally, the National Water Agency (ANA) generated a tender for the installation of 22 flexible ring net barriers in nine streams to protect life and properties of more than 60’000 inhabitants (Fig. 5). TDM S.A. got the work awarded and started the installation in January 2016. The dimensioning of the barriers is explained in the next section (cf. Section 3.2). One special application was installed in quebrada Carossio. The barrier has a width of 60 m with 6 posts and a barrier height of 6m. Hence, it is the second largest barrier in the world and the largest in South America.

(a) (b)

Fig. 4. Steep, incised slopes (a) overlooking Chosica's urban area and the unconsolidated material covering these slopes (b)

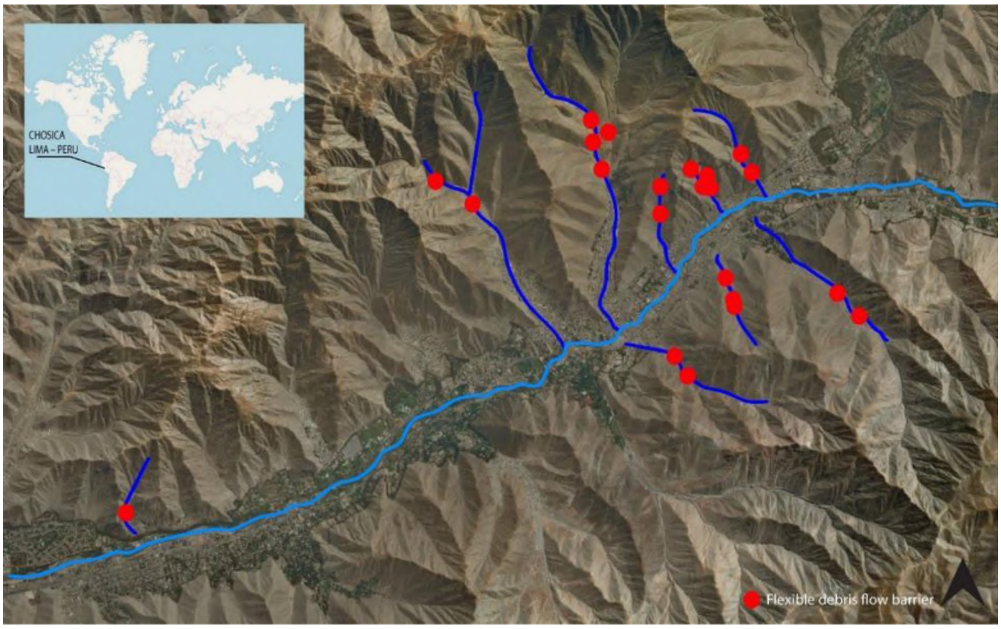


Fig. 5. Case study overview in Cuenca del Rio Rimac Distrito de Lurigancho, Chosica, Peru with 22 installed flexible debris flow barriers (red dots)

*Dimensioning with DEBFLOW*

Flexible standardized barriers, up to a barrier height of 6m, were dimensioned with DEBFLOW, Geobrugg's official dimensioning tool for debris flow. It is freely accessible for anyone on the website1. The software is based on FARO [*Volkwein, 2004*] and analyses the stability of the chosen barrier system (VX/UX-barrier), calculates appearing dynamic and hydrostatic forces during the filling process and overtopping [*Geobrugg, 2017*]. The software is a one-page format and built up of debris flow parameters, barrier specific parameters for each selected barrier, choice of standard barrier system, proofs of maximum dynamic loading and static loading as well as of the chosen standard system. Overall retention volume of all selected barriers gets calculated, based on three load cases taking into account the type of flow, granular or muddy. Special design was undertaken for the barrier in quebrada Carrosio, the largest flexible ring net barrier in South America, since the dimensions required from the channel geometry exceeded the standard dimensions of flexible ring net barriers.

*Installation*

Installation work took 2.5 months to complete and was accomplished between January and March 2016. During this time, potential debris flow streams were not activated because of no precipitation in the area. Details of installation are presented below such as scour protection of posts foundation for the UX-barriers and the special designed abrasion protection for the top support rope (see Fig. 5 and 6). Depending on the hydraulic conditions and the geometry of the different streams, UX or VX barriers were installed (Fig. 7), as single barrier or in a multi-level combination. The largest barrier was set up in a multi-level setting (Fig. 8).

(a) (b)

Fig. 6. (a) Scour protection around the posts for UX-barriers; (b) abrasion protection for the top support rope

(a) (b)

Fig. 7. UX- barriers with two posts in the channel bed (a) and VX barrier in a narrower channel (b)

(a) (b)

Fig. 8. Multi-level installation of flexible ring net barriers (left). The highest barrier is the largest in South America (right)

*Debris flow events*

The first debris flows after installation happened a year later, in January 2017. Up to then, all barriers have retained debris in variable amounts. On average, their retention level has been around 4’600 $m^3$. Subsequently, in February 2017, Peru was hit by great storms which caused even further, large, debris flow events. The flexible debris flow barriers kept fulfilling their function of retaining debris. The multi-level system was efficient since the barriers further downstream were not completely filled and still offer good retention capacity, for potential following debris flows. During the debris flow events post supports and cable supports got partially eroded. Hence, maintenance work on these elements was done. Eroded parts were rebuilt with new foundations, brakes and cables were replaced. Further, the barriers need emptying when the material is dry and stable. It can be cleaned with an excavator from behind or in certain conditions, when all safety requirements are met, from the front. Fig. 9 illustrates the overall process for the barriers, from installation to filling to maintenance, ready for the next debris flow events.

## Conclusion

Since the 1:1 field experiments and the publication of the design concept for flexible debris flow barriers, many projects have been successfully installed in the last ten years, the Peru case study being one of several examples worldwide. The protection system with multiple flexible ring net barriers fulfilled successfully the prevention purpose of the vulnerable area situated further downstream. After geological and hydrological studies, some fieldwork and thanks to the standardization and dimensioning with DEBFLOW, a flexible ring net barrier system composed of a total of 22 nets lead to an impressive protection concept. The CE marked barriers were rapidly installed within 2.5 months. Compared to classical protection structures, such as large concrete check dams, the flexible ring net barriers are much easier to install in the ravines, with evidently less material to be handled on the slope. Furthermore, they integrate themselves very well into the landscape (see Fig. 10), can even be installed in landscape protection zones and finally the carbon footprint is more advantageous in comparison to concrete solutions (IBU report, 2008). As observed after the first debris flow events, maintenance of the structure can be done easily and presents an overall cost-effective and elegant solution.

Fig. 9. Before (2016) and after the debris flow event (2017) and subsequent maintenance (2018) for the stream San Pedregal (above) and Carrosio (below)

(a) (b)

Fig. 10: two examples to illustrates the blending in oft he the flexible ring net barriers into the landscape making them almost invisible (blue arrow indicates barrier on the left)

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