The Krvavec bottom cabin lift station protection against torrential hazards by a new slit check dam and a series of flexible net barriers

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Abstract In May 2018, during a heavy local rainfall, a debris flood transported some 20000 m³ debris and destroyed torrential structures and damaged the bottom station of the Krvavec ski resort cabin lift. The return period of the local rainfall event was estimated to be above 50 years. After immediate mitigation measures in 2018 to remove deposited debris and clean the station, a technical documentation was prepared in 2019-2021 for a more detailed mitigation in order to protect the area from future debris floods and potential debris flows. After reconstruction of destroyed torrential control structures in the lower section, a large reinforced concrete slit check dam was planned at the confluence of the two main tributaries: Lukenjski and Brezovški graben. Its retention volume is 14000 m³ and its capacity to stop the inflowing debris will be supported by a series of flexible net barriers in the two tributaries, 12 barriers in total. Their height ranges from 3 to 6 m and their span from 9 to 25 m. This paper presents a good example of the holistic approach how to control erosion processes that results in small landslides and granular/hyperconcentrated flows.

Keywords debris floods, mitigation measures, RAMMS, ring nets, Slovenia, flexible barriers

Introduction

Substantial parts of Slovenia are subjected annually to landsliding (Mikoš et al. 2004). Different forms of mass movements (e.g. Jemec Auflič et al. 2017) are triggered mainly during strong local storms with heavy precipitation, after prolonged rainfalls, or during and after strong earthquakes. Such events are focus of numerous research activities (Mikoš 2020), but also require for engineering mitigation works in hazard areas. In Slovenia, various torrential hazards are threatening also infrastructure, among others also touristic infrastructure. Since tourism is an important economic sector in Slovenia, safe operation of any infrastructure in touristic destinations is of paramount importance for sustainable tourism and individual safety of tourists during leisure and holidays, including indoor and outdoor sport activities and recreation. This paper describes a torrential event in May 2018, when a strong local thunderstorm damaged the bottom cabin lift to the Krvavec ski area in N Slovenia, and its mitigation to secure its safe operation during and after strong local thunderstorms triggering debris floods and debris flows (Sodnik et al. 2021).

Materials and Methods

The Krvavec ski area in N Slovenia

Krvavec Mountain is a ski resort in the Kamnik-Savinja Alps (northern Slovenia) and stretches from 1450 to 1971 m a.s.l. It is a high Alpine ski resort having its own artificial snow producing system, being therefore potentially resilient also for incoming climate changes. The first ski lift was constructed in 1958. With 29 km of ski slopes, it is one of the largest ski resorts in Slovenia. The main approach for the resort is the cabin lift, that was completely reconstructed in late 90's. Due to its high altitude, the Krvavec ski resort is very popular and the operational and safe cabin lift is crucial for its operating and further development.

Rainfall and debris flood event in May 2018

On May 30, 2018, an intense rainfall event occurred in the Krvavec area. Approximately 50 mm of rain in 30 minutes was recorded at the Krvavec weather station at 1740 m a.s.l. The rainfall intensity for 30min duration was estimated as 50 to 100-year return period event. Numerous small landslides occurred and resulted in mass flows that travelled downstream in the Brezovški and Lukenjski graben. Around 10000 m³ of the debris from the Brezovški graben was deposited around the bottom station of the Krvavec cabin lift, which was partially damaged (Fig. 1).

Figure 1 The Krvavec bottom station of the cabin lift after May 2018 event.

Fortunately, the debris material from the Lukenjski graben was deposited on the flatter part of the channel, upstream from the confluence with the Brezovški graben. Shortly after the May 2018 event, Slovenian Water Agency approached to the mitigation works. After first field interventions (i.e. cleaning of deposits), geological survey was carried out and a conceptual design was prepared. After a formal acceptance of the proposed technical solutions, final technical design for the proposed mitigation works was prepared.

Results

Geological investigations

After the first field interventions, geological survey of the area was carried out, focusing on the estimation of amount of debris material that could mobilize in future events. Geological map with critical sediment sources areas was prepared. General characteristics of the May 2018 event source area, transport of the material and lithological characteristics of accumulated material indicated that event characteristics were more typical for a hyperconcentrated flow (i.e. debris flood) rather than for a debris flow. The source area of deposited material was not an individual landslide, but rather a longer torrent section where erosion and small side slumps occurred. Based on the field survey, it was estimated that events with similar magnitudes could occur in the future. More detailed results are presented in the literature (Bezak et al. 2020).

Hydrological investigations and debris flood modelling

Hydrological model, using HEC-HMS was prepared to simulate runoff conditions in the Brezovški and Lukenjski graben. The peak discharge Q100 was estimated for further use in the design process of mitigation works. The numerical simulation model RAMMS-DF was applied to simulate May 2018 event. The main aim of modelling was to obtain debris flow pressure on structures and flow velocities. The model was calibrated based on the position and volume data about deposited debris material. More detailed results are presented in literature (Bezak et al. 2020).

Proposed mitigation measures

Conceptual design suggested three main mitigation measures: i) restoration of regulation of the Reka torrent downstream from Brezovški and Lukenjski graben confluence; ii) a new large check dam (barrier) with large sediment trap; iii) erosion control measures on the Brezovški and Lukenjski graben to prevent large sediment and erosion outbursts in the future.

Final execution designs were prepared for all three stages. Restoration of the Reka regulation (check dams, rip rap bank protection) was carried out in 2021. New large slit dam with 14000 m^3 sediment deposit capacity with associated measures presented in Fig. 2 is in the phase of building permit and land acquisition and is planned for construction in 2^{nd} half of 2022 or in 2023.

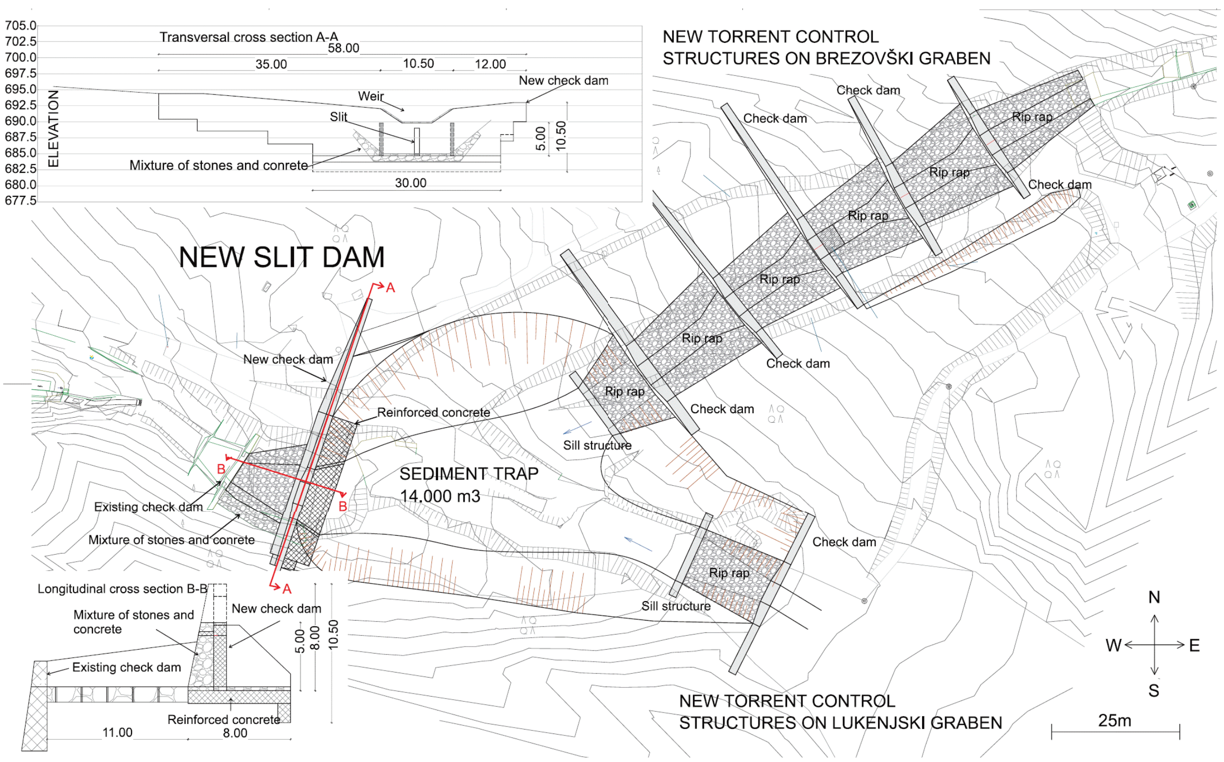

Figure 2 The slit check dam location and its main characteristics with its the transversal and longitudinal cross section. Spacing among contour lines is 2 m. Additional structures that are to be built are also shown in the figure (e.g. several sill structures).

Flexible net ring barriers proved to be a successful countermeasure for shallow landslides and debris flows (Geobrugg 2022a). Based on these experiences, a series of flexible net barriers is planned in the channels of the Brezovški and Lukenjski graben (Fig. 3), to prevent side erosion (bank collapses, slumps) and thus to limit sediment supply from sediment sources. Eight flexible barriers are planned on the Brezovški graben (Fig. 4) and four on the Lukenjski graben. Height of the barriers varies between 2,5 and 6 m and the sediment trap capacity between 100 and 800 m^3. Top width of the barriers varies between 9 and 25 m.

All the barriers were designed and dimensioned using DEBFLOW online tool, developed by Geobrugg (Berger et al. 2021). The design of the barriers was modified because the deposits are not intended to be removed after the events, but the main purpose of the barriers is to reduce channel slope, reduce velocities and support unstable channel banks. Because of this specific design, not all barriers are designed for debris flow impact, but all of them are designed for overflowing forces. The upstream barriers and the barriers with larger distance to next upstream barriers are designed for debris flow impact, which is one of the possible scenarios in the phase where barriers will be filling up with sediments. The final state of the barriers will be, when all of them are filled up, torrential bed slope reduced and bank erosion mostly mitigated. Based on the topographic characteristics, VX type of barriers (Fig. 5) are chosen. Some of them were customized with additional ropes and anchors, since there was no need to use stronger, more resistant nets, but only to add some ropes to fulfil all the design requirements (stability, resistance).

The downstream section of the Lukenjski graben is accessible by road, but the upstream part is not. Therefore, special equipment will be used for the construction of the 4 barriers in the Lukenjski graben. The Brezovški graben, on the other hand, is accessible only on foot. Therefore, an old forest road will be reconstructed to get close to the channel. Several logging lifts will be installed to transport the construction material to the construction sites, and most of the work will be done manually, because it will not be possible to get the excavator to the exact locations of the most of the barriers in the Brezovški graben.

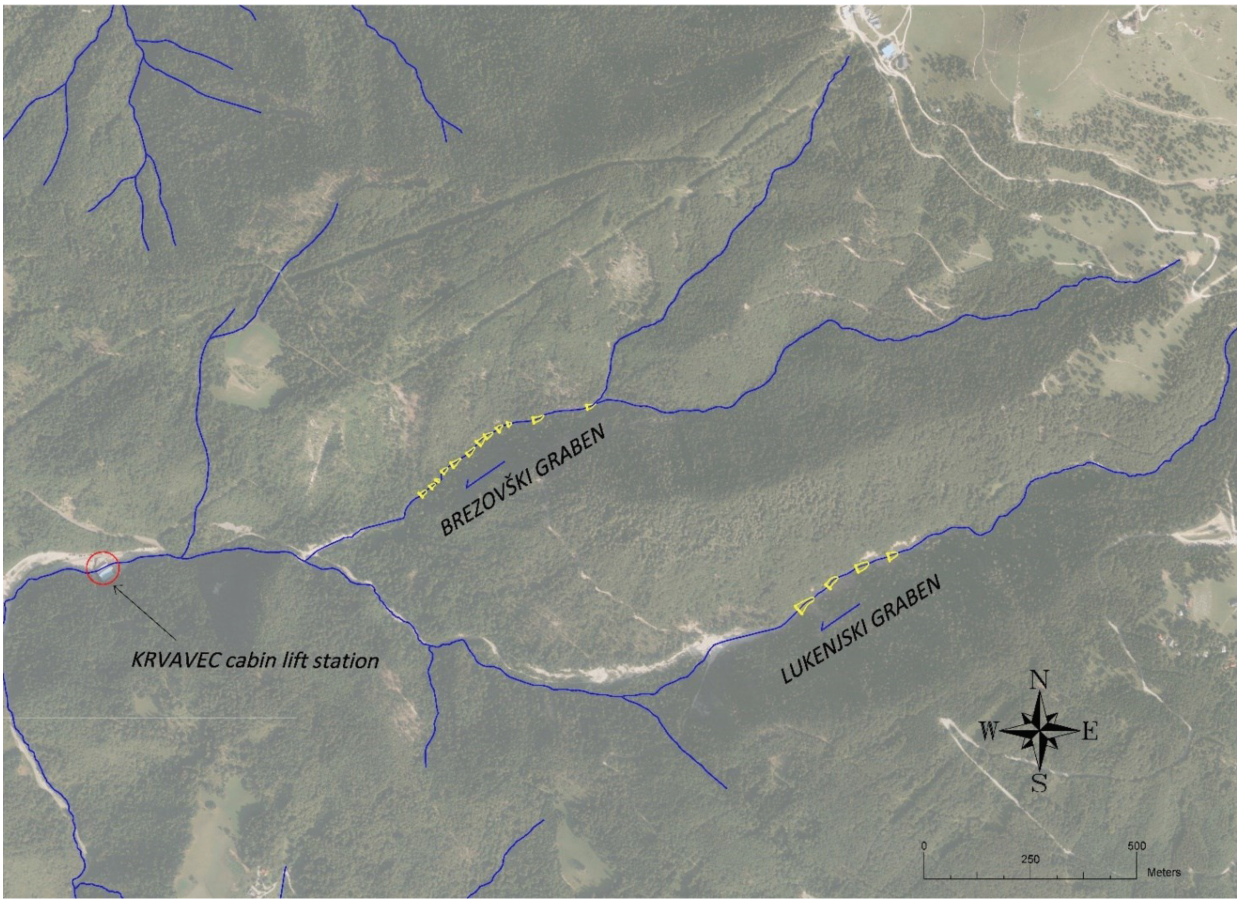

Figure 3 Digital ortophoto with Brezovski graben, Lukenjski graben and planned flexible barriers (yellow marks).

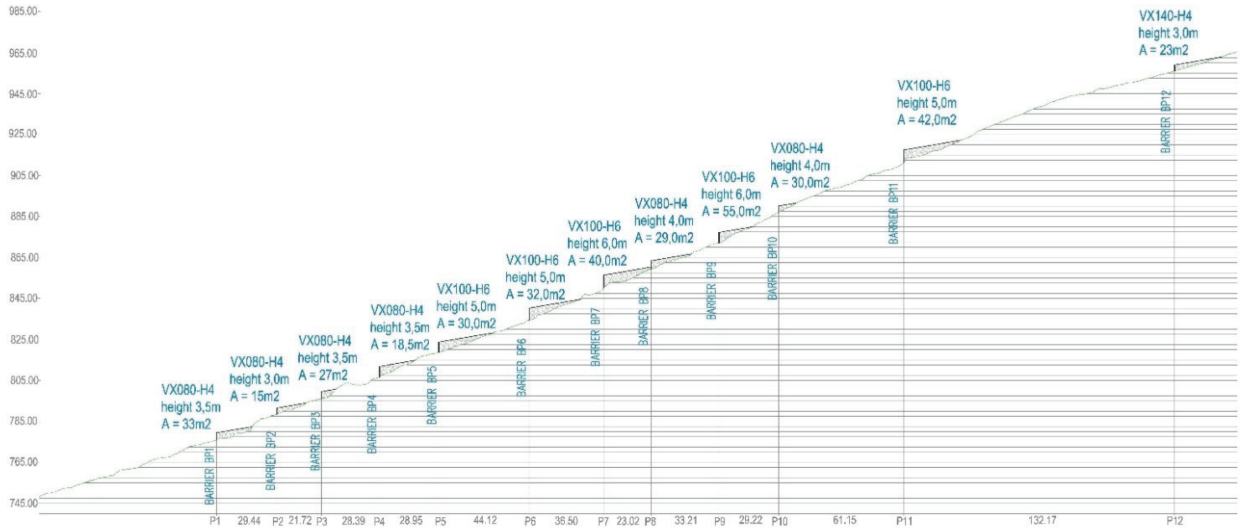

Figure 4 A longitudinal profile of the Brezovški graben with the locations of the 8 flexible net barriers.

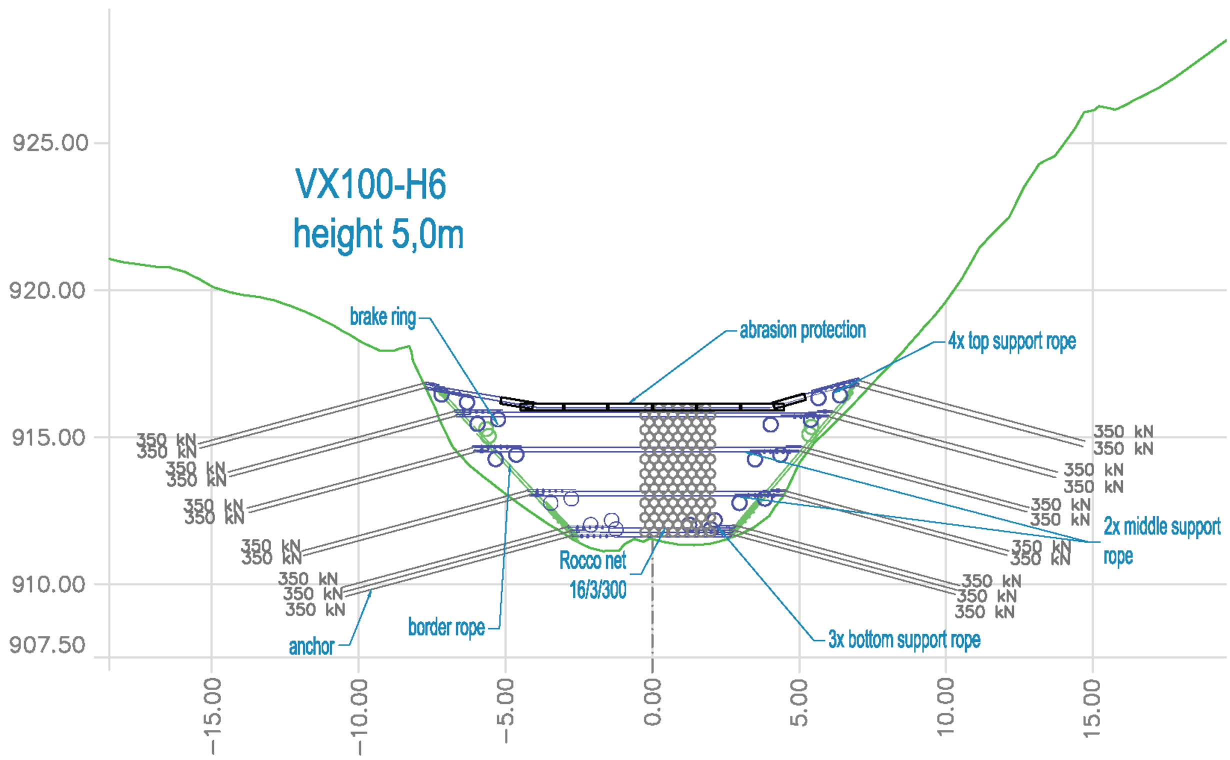

Figure 5 Example of a designed VX barrier.

Debris flow monitoring

The proposed mitigation works were soon also seen as a good opportunity to put research into practice by jointly developing a field debris flow observatory for a better understanding of debris flow dynamics and its interaction with protection structures.

Geobrugg GUARD and debris flow dynamics

The GUARD is a waterproof small device (2.6 kg), simply installed on the suspension rope of every protection barrier (Geobrugg 2022b; Fig. 6). Since it is packed with a selection of sensors which transmits environmental and physical data over a mobile network (GSM / UMTS / LTE) for decades, rockfall or debris flow events are clearly logged. One needs to correlate the locally measured weather data (wind, air temperature, precipitation, ...) with the logged data in the Guard.

Figure 6 Example of the Geobrugg Guard installation (Geobrugg 2022b).

For the purpose of this project, several Guards will be installed on protection barriers in the Brezovški graben to:

- estimate corrosion of the nets,
- detect single debris flow events (including single surges) by measuring impacts on the barriers up to 200 g and forces in the barrier ropes up to approximately 300 kN, knowing orientation of the Guard.

The field site of a protection barrier will be supported by video monitoring using simple hunting trail cameras used for wildlife photography. Such cameras can be triggered by movement of a debris flow just before it hits the protection barrier. Video surveillance will enhance the understanding of debris flow dynamics in the retention area above each net barrier.

Several occasional field measuring campaigns are planned to estimate the volume of retained debris after each debris flood respectively debris flow. Different techniques may be applied for this purpose, such as small drones (UAV), stereo photogrammetry or terrestrial laser scanning.

Concrete mixtures abrasion monitoring

The durability of torrential protection structures against torrential hazards is a function of environmental factors (such as air temperature, insulation, snow and rain, frost and chemical weathering, impacts of rocks or debris, etc.…) as well as the materials used for their production (such as concrete durability, steel corrosion, wood decay).

Positive experiences with regard to abrasion durability of concrete mixtures used for hydraulic structures were gathered in the past (Kryžanowski et al. 2009; 2012). Therefore, their upgrade is planned by an investigation in the harsher torrential environment governed by debris floods and debris flows rather than by suspended loads, as it was the case in the past in the Lower Sava River. For such a concrete durability tests, one needs to know exact mechanical loads that are causing abrasion. Such field tests correspond well with the standardised laboratory test for underwater abrasion of concrete (ASTM 2006).

Within the framework of this project, in-situ measurements of concrete abrasion resistance will be performed. The following steps will be executed:

- casting of concrete plates in a laboratory, using different recipes. The foreseen size is 50 x 50 cm due to transport reasons. Up to four different recipes are to be prepared, using expertise from on-site measurements on the Lower Sava River (Kryžanowsky et al. 2009). Two replicates will be prepared for each concrete type, using also a typical concrete mixture to be normally applied in torrent control works in Slovenia, as well as some advanced concrete mixtures with enhanced abrasion resistance using micro silica and steel fibers.
- placement of the concrete plates in a steel frame on the torrential bed in the Brezovški graben upstream of the upstream-most located net barrier.
- occasional measurements of the abrasion of plates will be performed in-situ, using precise techniques to differentiate changes onthe order of 0.1 mm.
- plates will be finally removed and weighted in a laboratory to determine the exact weight changes due to abrasion.
- using data on debris deposited upstream of the net barrier, estimated sediment transport rates will be gathered and correlated with the abrasion rates of different concrete mixture types subjected to real debris flows and hyperconcentrated flows in the Brezovški graben.

Conclusions

The Krvavec May 2018 case study has shown the true vulnerability of existing touristic infrastructure in Slovenia due to natural hazards. The proposed mitigation measures will decrease the rest risk and potential damages for future torrential events triggering fast flowing phenomena such as debris flows or debris floods. Under different climate change scenarios, it is our aim to adapt to more extreme weather events and to recognise existing risks in order to minimise risk gaps.

The Sendai Framework for Disaster Risk Reduction 2015-2030 asked to apply science, technology and research in the field of disaster risk reduction. A small contribution to these world-wide efforts should be our planned field observatory that will transfer remotely gathered data to us via mobile network for maintenance and inspection planning and early warning purposes. We hope to be able to report on its successful installation and initial results at the next ReSyLAB Symposium.

Acknowledgments

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Both projects were also approved by the International Programme on Landslides (IPL) as the IPL-225 and IPL-226 Project, respectively (http://iplhq.org/category/iplhq/ipl-ongoing-project/).

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References

ASTM C 1138M-05 (2006) Standard Test Method for Abrasion Resistance of Concrete (Underwater Method). Annual Book of ASTM Standards, vol. 04.02. American Society for Testing and Materials, West Conshohocken. pp. 621-624.

Berger C, Denk M, Graf C, Stieglitz L, Wendeler C (2021) Practical guide for debris flow and hillslope debris flow protection nets. WSL Berichte. 113: pp. 79 https://www.wsl.ch/fileadmin/user_upload/WSL/Publikationen/WSL_Berichte/WSL-Berichte/pdf/Ber-113_2021-Practical_guide_for_debris_flow-_published_version_.pdf

Bezak N, Jež J, Sodnik J, Jemec Auflič M, Mikoš M (2020) An extreme May 2018 debris flood case study in northern Slovenia: analysis, modelling, and mitigation. Landslides. 17(10): 2373–2383. https://doi.org/10.1007/s10346-019-01325-1

Geobrugg (2022a) Debris Flow & Shallow Landslide Protection - project overview. https://www.geobrugg.com/en/Debris-Flow-Shallow-Landslide-Protection-77515,7860.html [Last accessed: 19 January 2022].

Geobrugg (2022b) Geobrugg GUARD: Remote Status Monitoring. https://www.geobrugg.com/en/Geobrugg-GUARD-157047,7859.html [Last accessed: 19 January 2022].

Jemec Auflič M, Jež J, Popit T, Košir A, Maček M, Logar J, Petkovšek A, Mikoš M, Calligaris C, Boccali C, Zini L, Reitner JM, Verboveš T (2017) The variety of landslide forms in Slovenia and its immediate NW surroundings. Landslides. 14(4): 1537-1546. https://doi.org/10.1007/s10346-017-0848-1

Kryžanowski A, Mikoš M, Šušteršič J, Planinc I (2009) Abrasion Resistance of Concrete in Hydraulic Structures. American Concrete Institute (ACI) Material Journal. 106(4): 349-356.

Kryžanowski A, Mikoš M, Šušteršič J, Ukrainczyk V, Planinc I (2012) Testing of Concrete Abrasion Resistance in Hydraulic Structures on the Lower Sava River. Strojniški vestnik – Journal of Mechanical Engineering. 58: 245-254. DOI:10.5545/sv-jme.2010.217

Mikoš M (2020) After Stože Landslide: Part I – Development in Landslide Research in Slovenia. Acta hydrotechnica. 33(59): 129-153. https://actahydrotechnica.fgg.uni-lj.si/paper/a33mm1.pdf

Mikoš M, Brilly M, Ribičič M (2004) Poplave in zemeljski plazovi v Sloveniji = Floods and Landslides in Slovenia. Acta hydrotechnica. 22/37: 113-133. https://actahydrotechnica.fgg.uni-lj.si/paper/a37mm.pdf

Sodnik J, Bezak N, Jež J, Jemec Auflič M, Mikoš M (2021) Mitigation measures in the Krvavec ski-resort area (N Slovenia, Europe) against debris floods and debris flows. Extended Abstracts of the 14th Congress INTERPRAEVENT 2021, 31 May – 2 June 2021. Bergen, Norway. pp. 344-346. http://www.interpraevent.at/palm-cms/upload_files/Publikationen/Proceedings/IP_2021_EA.pdf