Integrated natural hazards protection concept Vitznau LU - Case study Plattenbach

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ABSTRACT

Vitznau (LU) is located at the foot of the south flank of the pre-alpine Rigi mountain. Eight debris-flow and flood prone torrents run through the village into the Lake Lucerne. The work presented herein focuses on the Plattenbach. Within the revision of the integrated protection concept numerical simulations for debris flow and floods were incorporated into the planning and design of protection measures. This case study illustrates this approach which is still not standard practice in Switzerland. The effectiveness of debris-flow mitigation structures was successfully evaluated using the new No-Flux feature of the RApid Mass Movement Simulation (RAMMS). The original layout could be optimized in a hazard protection and economical aspect. Flood events with less sediment mobilization were simulated using the hydro-numerical model BASEMENT.

The final design of the retention dam provides protection against debris flows with up to 300-year return period. Additional measures on the fan allow for the conveyance of up to a 100-year flood. In case of extreme events a robust system behaviour is expected.

KEYWORDS

integrated hazard management; protection concept; debris flow; RAMMS; BASEMENT

INTRODUCTION

Present-day numerical simulation tools allow for in-depth evaluations of hazard scenarios. Their use lately gained increasing importance in hazard and risk assessment. While the number of simulation tools has enlarged, the need for improvement of their practical application still exists. Especially the often extensive calibration of model parameters and the interpretation and further use of simulation results remains challenging. This paper presents a case study of an integrated natural hazard protection concept in which numerical simulations were used in an early project stage to evaluate existing measures and assist the design of new structures.

The village of Vitznau (LU) is located at the bottom of the pre-alpine Rigi mountain in Central Switzerland. Eight steep mountain torrents run through the village. All torrents are prone to debris flows. Reworked hazards maps revealed protection deficits, showing weak points along the torrents. Based on these findings a risk-based prioritization by the Canton of Lucerne

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reduced the project to Altdorfbach, Kalibach, Widibach and Plattenbach. This paper focuses on the Plattenbach. The project perimeter also includes the adjoining Mühlebach (Fig. 1) for flood processes.

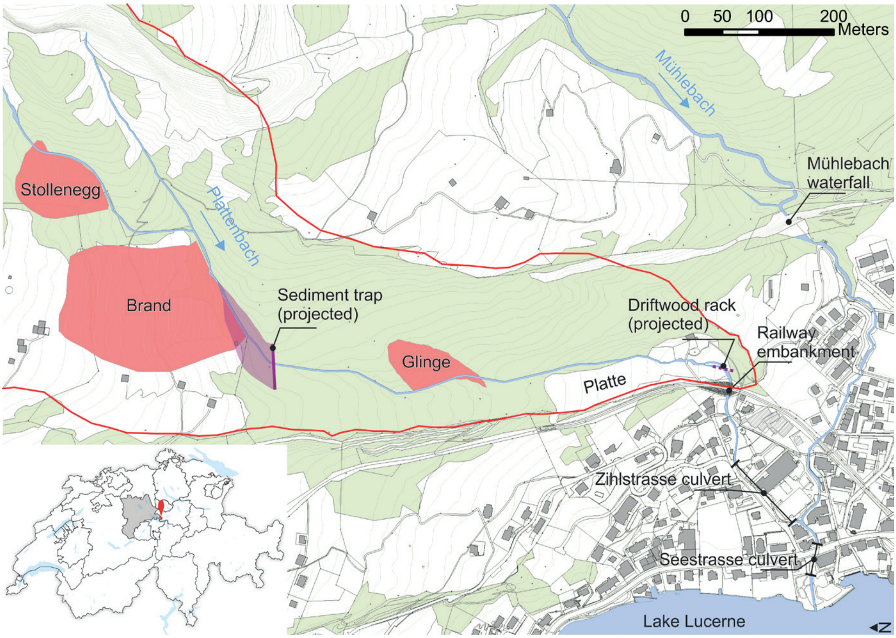

Figure 1: Overview of Plattenbach catchment area (red line); landslide areas marked in red.

The Plattenbach drains part of the steep southern flank of the Rigi. The bedded psephites on the southern flank are covered by detritus of variable thickness. Three instable zones "Stollenegg", "Brand" and "Glinge" (Fig. 1) are prone to landslide activity. Main and most active slide area is "Stollenegg". In case of long-lasting precipitation an acceleration of the sliding process is expected. The sediments transform to channelized debris-flows, estimated surge volume and maximum discharge are shown in Tab. 1. The channel runs predominantly on bedrock, is partially deeply incised, and passes through several narrow points. After crossing the railway embankment of the Rigibahn the Plattenbach runs for about 120 m in a culvert before the confluence with the Mühlebach. The last bottleneck is the culvert under the main road shortly before it flows into the Lake of Lucerne (Fig. 1).

A total of three culverts on the fan and natural narrow points in the transit section limit the conveyance of floods and debris-flow surges. Debris or driftwood clogging at these narrow points poses a large damage potential for the today densely populated fan. As observed in the

Table 1: Flood and debris-flow data for the Plattenbach. Values in brackets are Mühlebach flood discharges and bed-loads. Data from Holinger AG & NDR Consult (2013)

Return period	30-year	100-year	300-year	Extreme
Flood event				
Discharge [m^3/s]	12 *(+10)*	20 *(+19)*	32 *(+26)*	42 *(+34)*
Bed-load volume [m^3]	10 *(+1'000)*	200 *(+2'000)*	800 *(+7'000)*	4000 *(+20'000)*
Debris flow				
Total volume [m^3]	5'040	16'700	31'300	79'000
Surges [-]	2	3	4	3
Surge volume [m^3]	2'520	5'567	7'825	26'333
Peak Discharge [m^3/s]	70	130	170	420

2005 event discharge form the Mühlebach and backwater effects from Lake Lucerne need to be considered as well.

Only a few historical events are known for the Plattenbach. Two of them are documented. The one from 1910 is the largest recorded event. In 2005 a similar sequence of events with lower debris volumes and minor consequences took place. In both cases intense and long-lasting rainfall with a 100-year return period caused slope destabilization in the “Stollenegg” area. In 1910, about 15’000 m^3 of the total landslide mass of 30 – 40’000 m^3 formed a debris flow and deposited on the western part of the fan. No debris or log jam at the already existing railroad embankment was reported. Information on flow depth and flow velocity is missing. At this time the western part of the fan was almost not inhabited expect of the old school building that was damaged and the protestant church that was eventually touched but not damaged because of elevated and distal location. In August 2005 a volume of 500-1000 m^3 debris material was destabilized in the “Stollenegg” area. Toe erosion led to fluvial sediment transport and deposition in the culvert under the main road and at the outlet to the lake.

METHODS

In this project numerical models were used to assess different hazard processes in the initial state. In a second step the same numerical models were employed to evaluate the effectiveness of different natural hazard protection measures. The models were also used to assist the design of the protection measures.

NUMERICAL MODELS

The numerical models used in this work are the RApid Mass Movement Simulation (RAMMS) for debris-flow computations and BASEMENT for hydraulic flow and sediment transport simulations. RAMMS is based on the 2D shallow water equations and allows the computation of debris-flow runout on complex terrain (Christen et al. 2012). Debris flows are modelled as one single phase and the well-known rheological friction law of Voellmy-Salm is employed. The two empirical friction parameters were calibrated with the documented debris-flow event in 1910 (Hohermuth 2014). To account for different debris-flow mixtures the evaluation of protection measures was performed with a parameter range rather than single values (Hohermuth & Graf 2014). Digital Elevation Model (DEM) quality and resolution characterize the natural terrain and are therefore the key input parameters. The DEM used for the simulations is based on LIDAR data collected within the project and was verified in the field (Hohermuth 2014). The simulations in RAMMS were performed on a grid with 1x1m spatial resolution.

RAMMS 1.6.20 features so-called No-Flux cells, which allow to define impermeable flow areas such as buildings and retention dams. This feature was used for the first time in the work presented herein to evaluate protection measures i.e. deflection walls in a densely populated area. Fig. 2 shows the comparison of two different deflection wall designs. The simulations also allow to estimate the impact pressure and thus help with adequate design.

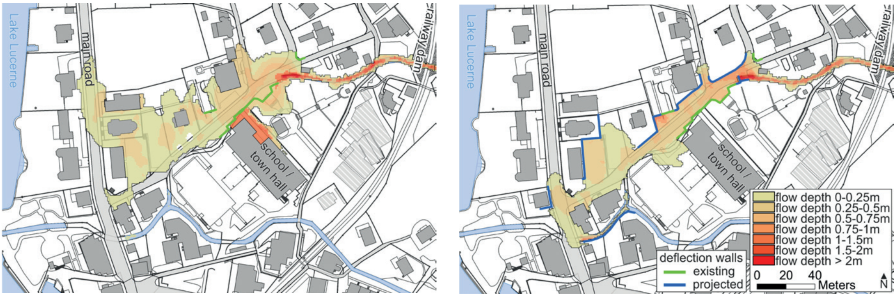

Figure 2: Comparison of debris-flow runout with and without deflection walls. Simulation results from RAMMS 1.6.20 with No-Flux cells. Deflection walls were dismissed in a later project stage.

BASEMENT is a simulation environment developed at the Laboratory of Hydraulics, Hydrology and Glaciology (Vetsch et al. 2013). For the computations within this project the 2D module BASEPlane V2.4 was used. Bed load transport can be modelled with various empirical equations. Gravitational transport is included with a simple geometric approach based on critical slope angles. There are no flood marks available for calibration and the hydrology of the 2005 flood event is only poorly documented. However, a rough calibration was performed to match the general sediment deposition behavior observed in 2005. Despite lacking a thorough calibration the simulations allow for a relative comparison of different flood protection measures.

OPTIMIZATION OF EXISTING DEBRIS-FLOW PROTECTION CONCEPT

Preliminary studies (Holinger AG & NDR Consult 2013) propose the following set of measures for debris-flow protection:

- Small check dams and slope drainage in the upper catchment “Stollenegg” (realized as emergency measure in 2012)
- Sediment trap with V = 10’600 m³ downstream of the “Brand” slope instability
- Reinforcement of railway embankment to allow for sediment retention, V = 2’600 m³

- Emergency corridor for events with more than a 100-year return period

The proposed measures were tested in RAMMS. The analysis showed that the original sediment retention volume is insufficient. In a 300-year debris flow –despite other measures – the remaining intensity would be above the acceptable limit. Based on simulation results the retention capacity of the check dam "Brand" was tripled to 33'000 m^3, what allows for a complete retention of sediments for the "Brand" and "Stollenegg" slope instability up to a 300-year return period.

A sensitivity analysis of the hydrograph shape and maximum peak discharge showed that the capacity of the channel in the transitional zone is sufficient even for extreme events. This superseded measures to increase the channel capacity which were considered in an earlier project stage.

The structural condition of the railway embankment makes a reinforcement to withstand debris-flow impact expensive. Backed up by numerical simulations it was concluded that debris flows originating from the "Glinge" slope instability can mostly be conveyed by the Plattenbach channel and do not lead to unacceptable intensities. Therefore measures in the transitional zone and sediment retention at the embankment were rejected. However to avoid clogging of the culvert a drift wood rack is intended upstream of the railway line.
The optimized concept consists of:

- Sediment trap with V = 33'000 m^3 downstream of the "Brand" slope instability
- Driftwood rack at the embankment culvert (no sediment retention)
- Emergency corridor for extreme events (R > 300-years)

In contrast to the original concept, the optimized concept provides protection up to a 300-year debris flow.

EVALUATION OF DIFFERENT FLOOD PROTECTION CONCEPTS

For regular flood events with moderate sediment mobilization additional measures are needed. The capacity of the culvert under the main road is 30 m^3/s for clear water flow. This is insufficient in a 100-year event (concurrence of flood events in both Plattenbach and Mühlebach). After the hydraulic jump at the confluence of Platten- and Mühlebach sediment deposition occurs. Additional deposition takes place in the "Seestrasse" culvert after the confluence due to the smaller channel slope. This could be observed during the flood event in 2005. The four different concepts shown in Fig. 3 were evaluated with the help of 2D simulations in BASEMENT. All concepts feature lateral walls (red in Fig. 3) and additional measures as follows:

- V1: Capacity increase: The conveyance of the culvert under the main road is increased. The culvert width is increased from 2.2 m to 7.5 m, this creates enough capacity even with large sediment deposits. Capacity increase at the schoolhouse bridge.

- V2: Side weir and diversion tunnel Mühlebach: Up to 10 m^3/s are diverted from the Mühlebach during a flood event.
- V3: Weir and diversion tunnel Plattenbach: A diversion weir inside the existing culvert "Zihlstrasse" diverts up to 15 m^3/s. Capacity increase at the schoolhouse bridge.
- V4: Flood depression overflow corridor: An flood corridor is created by an abatement of the main street. Additional object protection measures guide the water through the small park into the lake. Capacity increase at the schoolhouse bridge

The concepts were assessed based on the criteria hydraulics, performance in extreme events, ecological impact and feasibility and costs. The large land acquisition is the biggest downside of concept V1. Numerical simulations and sediment transport calculations showed that in V2 the maximum diverted discharge is limited to 10 m^3/s to avoid sediment deposition after the diversion. Thus an increase of the discharge capacity of the "Seestrasse" culvert is still needed what makes this the most expensive concept. The approach flow of the side weir in V3 is supercritical. In general, side weirs are not recommended for approach flow Froude numbers $F_o > 0.75$ due to their poor discharge characteristics (Bühlmann & Boes 2014). Sediment transport and the location inside the culvert further complicate the situation. Hydraulic model test would be required and the excess capacity during an extreme event is limited. Additionally concept V3 features high construction costs. The flood corridor in V4 will be in operation every 50-100 years. Discharges exceeding the capacity of the "Seestrasse" culvert are routed

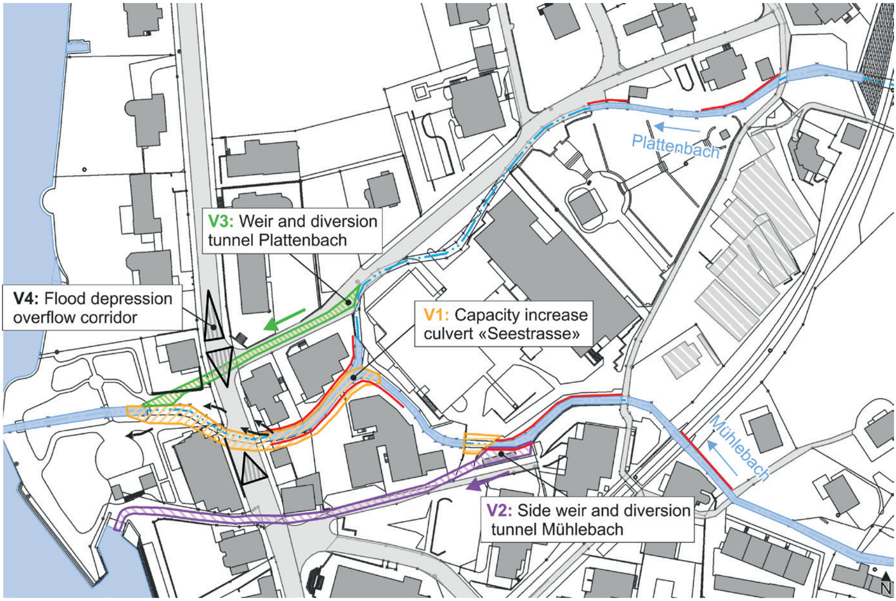

Figure 3: Illustration of four different protection concepts (versions V1 - V4).

through the flood corridor into the lake. The low construction costs and the robust behavior during extreme events make V4 the best option.

FINAL DESIGN

Measures against debris flow

The main requirements of the check dam “Brand” are retention, filtration and dehydration of sediments in case of debris flows and large floods. Due to spatial restrictions a conventional 20 m high concrete structure was chosen over a series of net barriers.

The retention volume is 33'000 m^3 for a sediment deposition slope of 7%. A 10 m wide overflow section is included in the middle of the 74 m long dam crest. To facilitate filtration and dehydration of debris a slot will be set up in the middle of the dam. Smaller flood events are conveyed by a gully at the bottom of the slot. An upstream driftwood / debris rack prevents early clogging of the slot during small events. The construction of a 700 m long new forest road allows access for construction and maintenance.

To account for potential driftwood from the lower catchment a new driftwood rack upstream of the railway culvert is planned. A total of 15 bars with a max. height of 2 m and a bar spacing of 0.8 m are planned. The right turn of the Plattenbach just upstream of the culvert allows for almost parallel approach flow. Thus backwater effects at the rack can be minimized.

Flood protection measures

The final design consists of lateral walls along the Plattenbach and the Mühlebach (max. height 1.5 m) as well as of object protection measures. The abatement of the main road to generate a flood corridor illustrated in Fig.4 exhibits good synergies with a simultaneous project to slow down transit traffic.
The capacity of the schoolhouse bridge across the Mühlebach has to be increased by the relocation of a small step and a local abatement of the river bed.

Management of the overload event

Although the measures provide protection up to a 300-year debris-flow event or a 100-year flood respectively, the overload scenario (extreme event) has to be evaluated. Numerical simulations show comparable flow depth and extent with and without the sediment retention “Brand” for extreme debris flows. It is assumed that the check dam is completely filled after the second surge and has no effect on third and last surge. Even the failure of the completely filled check dam does not lead to significantly higher intensities, because the intensities are in both cases mainly caused by the failure of the railway embankment. It can be concluded, that the measures do not aggravate the situation in an extreme debris-flow event. The project suggests the creation of an “overload zone” in which special regulations (building regulations, evacuation plans) apply.

Figure 4: Schematic illustration of the flood corridor. Diversion of discharge exceeding the culvert capacity into Lake Lucerne. Deflection walls drawn in red (Picture Holinger 2015).

For overload flood scenarios the capacity of the flood corridor is exceeded and low flood intensities occur along the main road. The flood corridor still has an attenuating effect during extreme events.

Cost Benefit Analysis

The total construction cost of all sediment and flood protection measures was estimated to 12.8 Mio. CHF whereas the risk reduction per annum was (based on EconoMe 2.0) approximated to 740’000 CHF/a (Plattenbach) and 232’000 CHF/a (Mühlebach). Thus a benefit-cost ratio from 2.9 (Plattenbach) and 6.0 (Mühlebach) is achieved with a design lifespan of 100 years and an interest rate of 2% (Holinger AG 2015).

CONCLUSIONS

Numerical debris-flow simulations in RAMMS were successfully employed to evaluate and optimize an existing protection concept. The tool allows to assess the effectiveness of protection measures. The optimizations allow for a higher protection level (up to 300-year return period) with the same cost-benefit ratio as the initial concept. The simulations help to test the robustness and resilience of the measures in an extreme event even though some limitations apply (Hohermuth & Graf 2014).

BASEMENT was used to investigate bed level changes during flood events. The simulations were used to assist the design of a flood corridor and additional measures which form a robust system that can handle floods with a broad range of sediment volumes.

REFERENCES

- Bühlmann, M., Boes, R.M. (2014). Lateral flood discharge at rivers: Concepts and challenges. Proc. Intl. River Flow Conference (Schleiss, A.J., De Cesare, G., Franca, M.J., Pfister, M., eds.), ISBN 978-1-138-02674-2, Taylor & Francis Group, London, UK: 1799-1806.
- Christen M., Bühler Y., Bartelt P., Leine R., Glover J., Schweizer A., Graf C., McArdell B.W., Gerber W., Deubelbeiss Y., Feistl T., Volkwein A. (2012). Integral Hazard Management Using a Unified Software Environment-Numerical Simulation Tool „RAMMS“ for Gravitational Natural Hazards. 12th Congress Interpraevent 2012.
- Hohermuth B. (2014). Integrales Schutzkonzept Plattenbach Vitznau – Murgangsimulationen mit RAMMS (Integrated Natural Hazard Protection Concept Plattenbach Vitznau – Debris-flow Simulations with RAMMS). Master Thesis, Swiss Federal Institute for Forest, Snow and Landscape Research WSL and Laboratory of Hydraulics Hydrology and Glaciology (VAW), ETH Zurich (in German, unpublished).
- Hohermuth B., Graf C. (2014). Einsatz numerischer Murgangsimulationen am Beispiel des integralen Schutzkonzepts Plattenbach Vitznau (The use of numerical debris-flow simulations – case study Plattenbach). Wasser Energie Luft 106(4), 285-290 (in German)
- Holinger AG, NDR Consult. (2013). Integrales Schutzkonzept Vitznauer Bäche (Integral Natural Hazard Protection Concept „Vitznauer Bäche“). Technical Report (in German).
- Holinger AG (2015). Integrales Schutzkonzept Plattenbach / Mühlebach (Integral Natural Hazard Protection Concept Plattenbach / Mühlebach. Technical Report (in German)
- Vetsch D., Siviglia A., Ehrbar D., Faccini M., Gerber M., Kammerer S., Peter S., Vonwiller L., Volz C., Farshi D., Mueller R., Rousselot P., Veprek R., Faeh R. (2006-2013). BASEMENT-Basic Simulation Environment for Computation of Environmental Flow and Natural Hazard Simulation. Version 2.4. ETH Zurich. Available from http://www.basement.ethz.ch