Small-scale study of Debris-Flows Interactions with a Lateral Debris Basin and Crossings: The Manival Torrent case study

Damien Alliau, Guillaume Piton, Guillaume Chambon, Anne-Sophie Drouet, Vincent Koulinski, Damien Kuss, Dominique Laigle, Vincent Mano, Clément Misset, Christophe Peteuil, et al.

To cite this version:

Damien Alliau, Guillaume Piton, Guillaume Chambon, Anne-Sophie Drouet, Vincent Koulinski, et al.. Small-scale study of Debris-Flows Interactions with a Lateral Debris Basin and Crossings: The Manival Torrent case study. 8th International Conference on Debris Flow Hazard Mitigation (DFHM8), Jun 2023, Torino, Italy. pp.02001, 10.1051/e3sconf/202341502001 . hal-04240864

HAL Id: hal-04240864
https://hal.inrae.fr/hal-04240864v1

Submitted on 13 Oct 2023

Small-scale study of Debris-Flows Interactions with a Lateral Debris Basin and Crossings: The Manival Torrent case study

Damien Alliau[1], *Guillaume* Piton[2], *Guillaume* Chambon[2], *Anne-Sophie* Drouet[3], *Vincent* Koulinski[4], *Damien* Kuss[3], *Dominique LAIGLE*[2,*], *Vincent* Mano[6], *Clément* Misset[5], *Christophe* Peteuil[1], *Sébastien* Roux[1], and *Pierre* Verry[6]

[1] CNR, Centre d'Analyse Comportementale des Ouvrages Hydrauliques CACOH, 4, rue de Chalon sur Saône, 69007 Lyon, France
[2] INRAE, UR ETNA, Domaine Universitaire, 2 rue de la Papeterie, BP76, 38402 Saint-Martin-d'Hères Cedex, France
[3] SYMBHI, Syndicat mixte des bassins hydrauliques de l'Isère, 9 Rue Jean Bocq, 38000 Grenoble, France
[4] E.T.R.M., 581 Route de Mont Carmel, Chef-Lieu, 73700 Les Chapelles, France
[5] Office National des Forêts - Direction Forêt & Risques Naturels, 9 quai Créqui, 38 000 Grenoble, France
[6] Office National des Forêts - service de Restauration des Terrains en Montagne de l'Isère, 9 quai Créqui, 38 000 Grenoble, France

Abstract. Small-scale models are useful tools to study the interactions between debris flows and structures and channels. Small-scale modelling of debris flows remains however complicated because of the complex rheology and scaling challenges of these geophysical processes. An on-going study of a debris basin and the downstream channel where two fords and a bridge are located is presented in this extended abstract. The studied torrent is the Manival catchment, located near Grenoble in France. We present the catchment features, the scientific questions studied, some preliminary calibration results describing the mixtures used to model debris flows as well as results from three debris-flood and two debris-flow runs. In essence, the model highlighted that the structure enable a large share of the bedload transport to pass downstream. Debris flows can be more or equally trapped depending on their rheology which controls the surges dynamics and the deposition slope in the debris basin.

1 Introduction

Retention basins are common mitigation measures against debris-flow hazards. Even if thousands of such structures exist in mountain areas of Europe and Asia, the interactions between those structures and debris flows and floods are insufficiently known and many open questions remain. Indeed field observation of such interactions are very rare. As a consequence, structures are designed empirically with simple criteria and often induce side effects as excess in sediment trapping possibly leading to downstream sediment starvation and high maintenance costs [1].

Although progressing rapidly, numerical models are not yet capable to comprehensively simulate the many processes involved in debris-flow trapping, *e.g.*, flow spreading, effect of grain segregation, interactions between boulders and open check dams. Numerical models tend to correctly capture some of these effects while neglecting others [2–4].

Small scale models remain thus interesting options to study structures and sites with complex topography and interactions with structures [*e.g.* 5–7]. In this paper, we present an on-going study using a small-scale model of the Manival torrent, namely its debris basin and the downstream channel that is crossed by two fords. The first and second sections of this paper present the main features of the catchment and the model. The last section describes preliminary experiments predesigning the flow mixtures, as well as two experiments of the study: more results will be available at the conference.

2 The Manival catchment

The Manival torrent is located in the Chartreuse mountain range about 10-km north of Grenoble, in the Northern French Prealps [8]. A more than 300 m-high Jurassic marly limestone cliff, along with thick colluvial deposits below rock-walls are source of debris flows. Its steep slopes (mean channel slope: 0.16 m.m-1; Melton Index: 0.62) and its high potential sediment supply make the catchment pretty active. The Manival torrent experiences bedload transport, debris floods and debris flow with, on average one major event every three years. Its catchment has a drainage area of 3.6 km² at the inlet of the modelled debris basin and downstream reach. Two monitoring stations are located in the torrent, one in the debris basin and another upstream [9,10].

To mitigate the associated risks, torrent control works have been implemented since the 1890s by the French torrent control service (ONF-RTM). Nowadays, the torrent is equipped with more than 160 check dams, dikes and a debris basin (located 45.271°N, 5.832°E). This basin has a length of about 100 m and is closed by an open check dam (Fig. 1). The check dams prevent the bed incision and at confining the flows inside a 10 – 20 m wide single channel.

---

[*] Corresponding author: dominique.laigle@inrae.fr

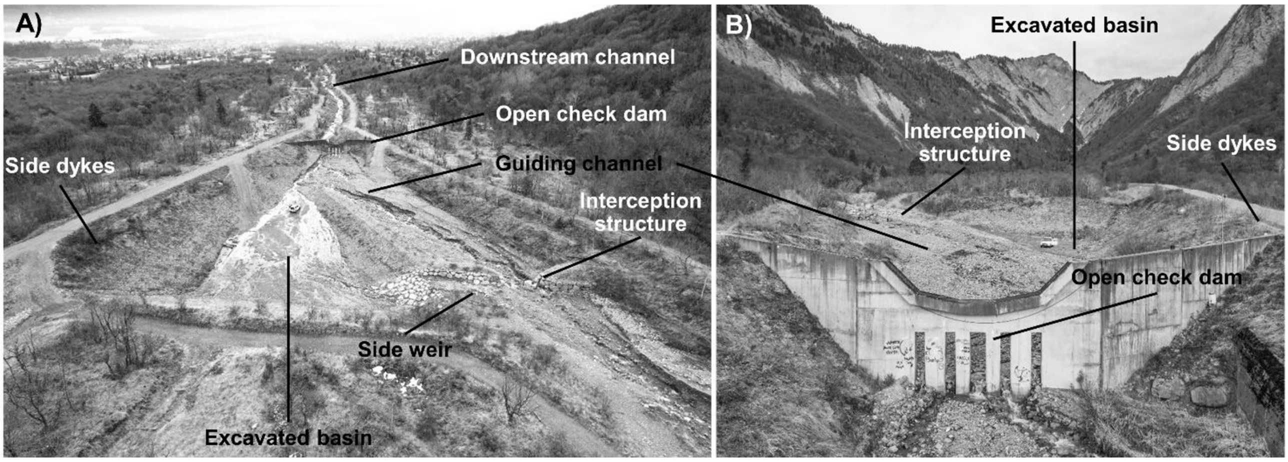

Fig. 1. Views of the Manival debris basin: A) view from upstream and B) view from downstream (courtesy of O. Lefebvre)

With its initial shape, the debris basin used to experience chronic sediment deposit during bedload and debris-flow events. Deposits were driven by its large width and a very gentle slope (7 % within the basin compared to 12-13 % upstream), in addition to the relatively small openings of the open check dam [11]. As a consequence, the debris basin was modified in 2018 to evolve toward a derivation configuration [1]: a guiding channel with a steeper, regular slope was added in the debris basin; an intermediate interception structure was built at the upstream end of the guiding channel; a lateral weir was also built guiding high flows toward the debris basin which is now located on the left bank and excavated deeply below the guiding channel level. The change of design was motivated by an incision of the channel that could reach up 10 m downstream of the debris basin [1]. The objective was to restore sediment connectivity for low intensity events while keeping a sufficient volume storage for rare events. During routine events, *i.e.*, low magnitude bedload transport events, flows are supposed to stay confined in the guiding channel allowing an almost full sediment connectivity. During debris flows, flows were expected to be redirected toward the side weir and be partially trapped by filling the basin.

Those adaptations may significantly change the protection system operation. In addition, the volume of the 100-year return period debris flow, which is estimated at about 30 000 m³, strongly exceeds the debris basin storage capacity that was estimated in the range 10 000 – 17 000 m³ depending on the deposition slope [12]. It is thus anticipated that a large share of the debris flows could be transferred downstream. Two fords and a bridge located on the downstream channel may be potential avulsion points because of the lower level of the lateral banks at these locations. Moreover, the small height of the banks at those places could lead to the uncontrolled flooding of riverine fields and houses in case of debris flood. The channel has a slope of about 12% near the debris basin, but it reduces to about 5% when approaching the bridge some 2 km downstream.

3 Objective of the study

Considering the context, the local basin agency (SYMBHI) and the torrent control office (ONF-RTM) decided to perform a small-scale model study: (i) to check whether the routine event transfer and the trapping of the project design event actually occur, and whether adaptations of the debris basin may optimize this functioning. Adaptations of the fords and bridges can also be studied to decrease flow levels and deposition trends; (ii) to better understand the deposition mechanisms (spatial and temporal dynamics of filling, effective storage volume, slope of deposition); (iii) to measure the ratio of supplied volume to the volume passing the debris basin and reaching the downstream channel as a function of the nature and intensity of events; (iv) to measure the flow levels at the debris basin, interception structure and its outlet barrier; (v) to serve as benchmark data to calibrate numerical models of sediment transfer throughout the basin and the downstream channel; and finally (vi) to convince stakeholders about the usefulness of debris basins with derivation configurations, in order to consider equivalent adaptations of the numerous debris basin facing similar problems of excessive trapping [1].

4 The experiments

The small-scale model study is performed at CNR hydraulic flows and structures laboratory located in Lyon (France). A small flume (Fig. 3) was first used to define the debris flow mixtures, later tested on a small scale model, both of them at a scale of 1:25 (Fig. 2).
For debris flows, the experiments were designed using the Froude number similitude, as well as similitude criteria assuming a Herschel-Bulkley rheology [13], which is assumed to be suitable for viscous muddy debris flows [*i.e.* 13], occurring in the Manival torrent.

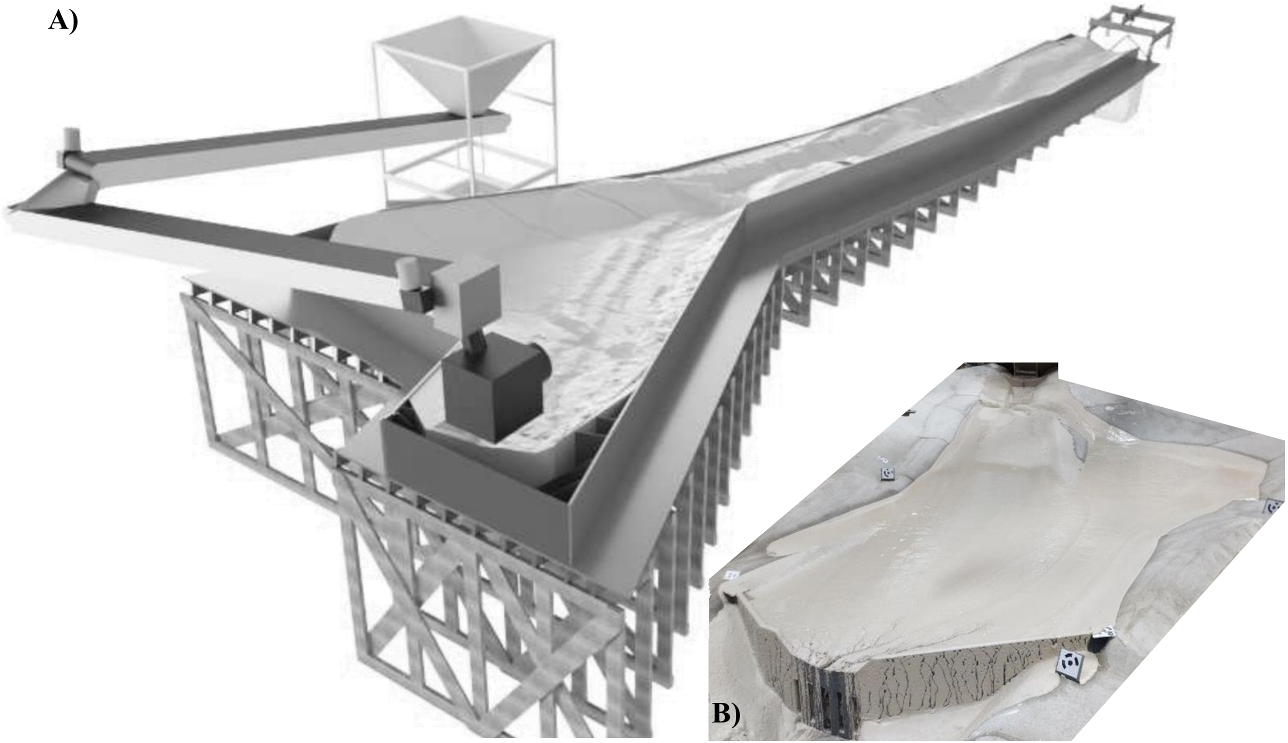

Fig. 2. A) Digital view of the small-scale model; B) View from downstream of the debris basin after a "fluid" debris flow run

Fig. 3. Calibration flume tests: propagation of A: fluid mixture, B: viscous mixture

4.1 The small flume tests

Mixtures were prepared with various content of water, clay (kaolin) and two sands (grain sizes: 0-1.1 mm and 3 mm). A 3 m-long, 0.18 m-wide flume was built to help calibrating the mixture (Fig. 3). Calibration tests were performed releasing 300 kg of mixture varying the contents of water, clay and sand and measuring flow wave properties (front velocity, height of the flow and residual deposit) over a slope of 13% corresponding to the actual channel slope.

The objective was to define two suitable mixtures mimicking (i) a rather fluid debris flow (criterion: yield-stress leading to 0.4 m-thick deposit in nature, roughly 0.018 m on the model). This was achieved using the following mass ratio: 31.3% of water, 18.8% of kaolin clay, 50% of 0-20 mm sand and gravel (Fig. 3A). (ii) Another more viscous debris flow (criterion: yield-stress leading to 1.5 m-thick deposit in nature, roughly 0.06 m on the model) was achieved using the following mass ratio:16% of water, 7.5% of kaolin clay, 76.5% of 0-20 mm sand and gravel (Fig. 3B).

4.2 The small scale model tests

The small-scale model has a variable width of 2.5 to 6.3 m and is 22.5 m long (Fig. 2). This length is equivalent to about 550 m at prototype scale. The actual distance between the inlet of the debris basin and the road bridge being about 2.2 km, the intermediate reaches located downstream of the basin were shortened. Overall, the model represents at prototype scale 60 m of the upstream channel, 112 m of debris basin, 95 m of downstream channel equipped with check dams, 80 m of channel with a ford on a check dam and 218 m of the downstream natural channel whose outlet is the road bridge. The mean slope is about 5% in this last section, and 12% on the upstream channel.

Several cameras filmed the runs, an ultrasonic sensor measured the flow level at the open check dam and a scale weighted the mass exported out of the model. The model banks are made of concrete and are thus non-erodible. The model bed is made of mobile sediment whose grain size distribution was scaled down from field samples (model median grain size: 1.36 mm).

Three debris flood experiments were performed with bedload transport fed by a hopper. They confirmed the trend observed in the field: namely, the new configuration with a guiding channel restores the bedload transport connectivity. If no jamming occurs at the open check dam, only about one third of the 15,000 m³ of bedload supplied by a 100-yrs debris flood event would be trapped in the debris basin, the rest being transferred in the downstream reaches with strong deposition in the 5 %-steep reach (only about 1,500 m³ is transported downstream of this mild reach). If a jamming of the open check dam occurs, up to 11,000 m³ of bedload is trapped in the basin and the remaining volume is transferred downstream of the model including some volume eroded in the bed through a "hungry water" effect.

After the calibration tests using 300 kg of the two representative debris-flow mixtures, runs were performed with the same materials for volumes corresponding to full scale 100 years return period events: 30,000 m³ at prototype scale, *i.e.* about 4 tons of material on the small-scale model (see e.g. Fig. 2B for the debris basin at the end of the first debris-flow run). Each run was performed releasing this volume in two surges coming from the two mixing tanks each preparing two tons of material. The two tests show similarities and differences as listed below (note that the prototype scale is used consistently in all descriptions).

In both cases, (i) the flow was released in 5 – 10 min leading to peak discharges of 100 – 130 m³/s. Although slightly higher than expected, this range is in between typical values expected for muddy and granular debris according to the empirical equation of [14]; (ii) the flow was partially diverted toward the side basin which trapped some material upstream of the open check dam; (iii) the open check dam was jammed by coarse grains almost immediately which was expected since the grain size (max diameter 20 mm) was more than half of the opening width (20 – 32 mm); and (iv) during the second surge, the flow depth largely submerged the open check dam.

The main difference between the fluid and the viscous mixtures were obvious effects associated to the higher mobility of the first mixture: (i) the debris basin trapped only about 8,000 m³ of the first while almost 22,000 m³ of the latter; (ii) this capacity is directly related to the steeper deposition slope of the viscous mixture (about 13%) as compared to the gentler deposition slope of the fluid mixture (4-6%); (iii) the fluid mixture was also faster (front velocity ≈ 5 m/s) than the viscous (front velocity ≈ 1.3 m/s), and (iv) the fluid mixture transferred debris flows much further since more than 8,000 m³ of material left the flume outlet (and about 3,000 m³ were kept in the feeding system to protect the downstream weighting system from an overloading) while no debris flow reached the flume outlet during the viscous mixture run: all material was either trapped in the debris basin or deposited in the downstream channel.

5 Concluding remarks & perspectives

This small-scale model study of debris flows is the first of its kind performed for engineering purpose for two decades in France. It is proving very useful information to better understand debris flow trajectories over protection structures with complex geometry. In the next phases, steps of adaptations of the debris basin and of the downstream channel will be performed. These adaptions will seek to optimize the debris flow spreading in the basin to maximize the trapping, and to adjust the ford and bridge geometries to minimize the probability of avulsion or bank overflowing.

At a later stage, the data acquired during the experiments (3D scan of the deposit during the flow and at the end, velocities and flow elevations) will be used to calibrate numerical models of both debris flows and bedload transport. These calibrated models will then be used to study further options and different geometry of the channel and structures.

References

1. Carladous, S., Piton, G., Kuss, D., Charvet, G., Paulhe, R., Morel, M. and Quefféléan, Y., Check Dam Construction for Sustainable Watershed Management and Planning, Wiley Online Library, 247–266 (2022).
2. Canelas, R. B., Domínguez, J. M., Crespo, A. J. C., Gómez-Gesteira, M. and Ferreira, R. M. L., J. Hydraul. Eng. **143**(9), 06017012 (2017).
3. Goodwin, S. R. and Choi, C. E., Comput. Geotech. **141**, 104503 (2022).
4. Piton, G., Goodwin, S. R., Mark, E. and Strouth, A., J. Geophys. Res. Earth Surf. **127**(5) (2022).
5. Speerli, J., Grob, M., Künzi, R., Wyss, P., Zimmermann, M. and Pozzi, A., In proceedings of the International Symposium Interpraevent, Dornbirn, Austria, 384–385 (2008).
6. Rickenmann, D., Karrer, T., McArdell, B. and Scheidl, C., in proceedings of the Seventh International Conference on Debris-Flow Hazards Mitigation, Golden, Co., USA, 414-420 (2019).
7. Scheidl, C., McArdell, B., Nagl, G. and Rickenmann, D., in proceedings of the Seventh International Conference on Debris-Flow Hazards Mitigation, Golden, Co., USA, 437-442 (2019).
8. Theule, J. I., Liébault, F., Loye, A., Laigle, D. and Jaboyedoff, M., Nat. Hazards Earth Syst. Sci. **12**(3), 731–749 (2012).
9. Fontaine, F., Bel, C., Bellot, H., Piton, G., Liebault, F., Juppet, M. and Royer, K., Collection EDYTEM, Monitoring en milieux naturels - Retours d'expériences en terrains difficiles, 213–220 (2017).
10. Piton, G., Berthet, J., Bel, C., Fontaine, F., Bellot, H., Malet, E., Astrade, L., Recking, A., Liebault, F., Astier, G., Juppet, M. and Royer, K., Collection EDYTEM, Monitoring en milieux naturels - Retours d'expériences en terrains difficiles, 205–212 (2017).
11. Piton, G., Fontaine, F., Bellot, H., Liébault, F., Bel, C., Recking, A. and Hugerot, T., in RiverFlow 2018 Proc. E3S Web Conf. 40, 1–8, EDP Sciences (2018).
12. ONF-RTM 38., Forêt domaniale du Saint-Eynard. Etude de Bassin de Risques. Division domaniale RTM du Manival., Service de Restauration des Terrains en Montagne de l'Isère (2016).
13. Coussot, P. and Laigle, D, Journal of Hydraulic Research **32**(4), 535-559 (1994).
14. Mizuyama T, Kobashi S, Ou G. In proceedings of the International Symposium INTERPRAEVENT, Bern, Switzerland, 99–108 (1992).