PUTTING A GRILL (OR NOT) IN SLIT DAMS AIMING AT TRAPPING DEBRIS FLOWS? LESSONS LEARNT FROM FRANCE

Guillaume PITON[a,*], Gilles CHARVET[b], Damien KUSS[b], Simon CARLADOUS[c]

**corresponding author email: guillaume.piton@inrae.fr*
[a] Univ. Grenoble Alpes, INRAE, ETNA, Grenoble, France
[b] ONF-RTM, Northern Alps Agency, Grenoble, France
[c] ONF-RTM, Direction National, Grenoble, France

ABSTRACT

Slit dams are typical structures used in torrent control to trap debris flows and debris floods. While the question of the interval between bars of a grill is widely covered by the literature, the more basic question of whether or not to put a grill in the slit dam is less clear. The Maurienne valley is a debris flow hotspot in France. Since the 1980s, several torrents in the valley were equipped with dams with slits 4-6 m wide, initially with steel grills. Most of the grills were removed after a few events. The first grills were initially set down to the slit bottom thus creating chronic sediment trapping during small events unlikely to cause damage. In addition, grills impacted by debris flows transporting huge rocky boulders, typically 3-6 m in diameter, were damaged if not fully destroyed. Nonetheless, debris flows were partially trapped because such huge boulders often jam in slits and suddenly obstruct them. This note reports why slit dams are no longer equipped with steel grills in the debris flow torrents of the Maurienne valley and in other sites with similar characteristics.

Keywords: Slit dam; boulders, SABO dam, grill failure

INTRODUCTION

Slit dams are typical structures used in torrent control and debris flow hazard mitigation schemes. In some locations, the slit is equipped with a metallic grill that can be a simple grill or a 3D frame structure (e.g., Japanese SABO dams). Before addressing detailed questions relating to the interval distance between bars that may eventually be implemented, it is first important to decide whether or not to use such a grill element. From the experience of the authors, one of the main concerns of design engineers is potentially designing open check dams such that they would self-clean in an uncontrolled way and would thus not retain material for design events. It is a reasonable concern but it often drives them to equip most openings with bars and grills, selecting small intervals between the bars. Interestingly, our discussions with maintenance engineers are most of the time related to the opposite concern: open check dams generally tend to trap too much sediment, generating regular and expensive maintenance operations, as well as side effects downstream including incision and bank erosion related to the so-called "hungry water effect". The cost-benefit analysis by Brochot et al. (2003) demonstrated that the open check dam of the Manival torrent generated so much incision in the fan channel downstream and required so many check dams to prevent it that the costs of structures aimed at fighting the side effects of the main structure was higher than the potential damage related to the open check dam that was avoided.

Guidelines say that debris flows passing through slits will likely jam it if the slit width is less than 1.5 – 2.0 times the grain diameters of the coarsest grains (Fig. 1) (Ikeya & Uehara, 1980, Watanabe et al., 1980, CAGHP, 2018).

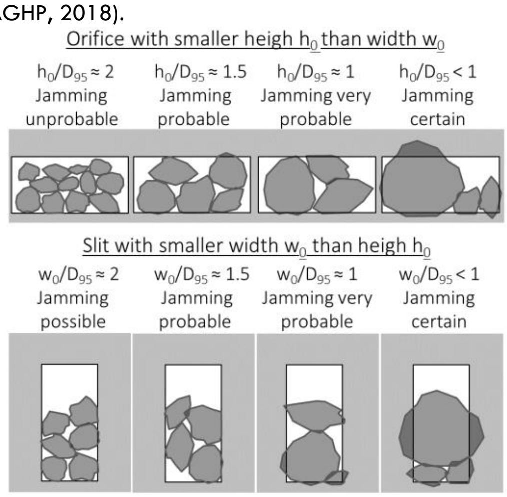

Fig. 1: Effect of increasing grain size on clogging probability of orifices (upper panel) and slits (lower panel). Jamming becomes likely for an opening size of D_{95} =1.5-2.0. Jamming occurs in slits for grains slightly smaller than orifices because arches between grains emerge more easily horizontally than vertically.

To the best of our knowledge, unwanted self-cleaning of open check dams is very rare. The few cases documented in the literature are related to torrents with bedload transport rather than debris flows (Bezzola, 2008; Vogl et al., 2016). With bedload transport, the coarsest elements are usually smaller than in debris flows. Slits and orifices can then be more than three times bigger than the size of the biggest transported boulders or cobbles, making jamming unlikely and potentially enabling self-cleaning.

In the debris flow torrents of the Maurienne valley, the main river is incised; furthermore, confluence usually has the capacity to buffer the volume of design events. In such streams, damage to channel structures, avulsion and hazards on fans often occur due to an excess in instantaneous discharge or channel blockage due to huge boulders, rather than by an excessive debris flow volume. Slit dams are relevant solutions to reduce instantaneous surge discharge, i.e., to release surges with lower peak discharges, and also to trap the biggest boulders. In this brief note, the upper slit dam of the Saint-Martin torrent (community of Saint-Martin-de-la-Porte, France) is used as an example of the lessons learnt after more than 30 years of experience. Although each catchment has a unique story, the authors could draw similar conclusions from other slit dams in the vicinity, e.g., on the Saint-Julien torrent, on the Saint-Antoine torrent, on the Ravoire torrent or on the Claret torrent.

This note firstly gives a brief presentation of the torrent and then describes the history of the adaptation of slit dams, as well as the lessons we have learnt from this experience. Most information comes from the detailed report ONF-RTM 73 (2013).

THE SAINT-MARTIN TORRENT IN BRIEF

The Saint-Martin torrent has a long history of debris flow hazards and mitigation works (Hugerot, 2020; ONF-RTM 73, 2013). The catchment experiences numerous erosion processes: avalanches, gullies, collapses and deep-seated landslides. It has the following features:

- Catchment size: 19 km²
- Max elevation: 2825 m.a.s.l.
- Melton index: 0.49
- Fan channel slope: 0.105 m/m

On average, the catchment experiences a debris flow event every seven years, though five debris flow events were observed between 2000 and 2013. Boulders of diameter 3-6 m can be found on channel banks and spread across the entire fan. ONF-RTM 73 (2013) estimated design events (Table 1).

Near the fan apex, two slit dams in series are located on the channel upstream of the lined section. The first slit dam is located 45°14'40.9"N 6°27'07.3"E and is further described in the following section. The second slit dam was built in 1996 by the highway company. It is located 450 m downstream from the first one. It is a 5 m wide, 8.5 m high slit dam with a retention capacity of 18,000 m³ assuming that the slope that forms after deposition has a gradient of 8.5 %. This second dam has never been jammed by boulders but flood marks visible up to the top of the slit prove that this second structure also generates debris flow surge dozing.

The downstream fan channel is located near residential areas, and crosses several local roads and the France-Italy highway on a canal bridge. The France-Italy railway passes below the torrent in a tunnel. The fan channel is currently lined on 50 % of its 700 m length with grouted riprap with bank protection partially in cut-stones. Built in 1889, its apron used to be lined with cut stone. In the 1980s, it was highly damaged and 27 concrete check dams spaced by 15 m were built and subsequently destroyed by a debris flow that lifted the deck of an upstream bridge and transported it in the channel. Five check dams remained out of the initial 27.

The confluence has enough room to accommodate large debris flow volumes: it is wide and the torrent is superelevated above the river.

Table 1. Design event features

Debris flow event	Volume (m³)	Return period (yr)
Frequent	30,000	≈ 10
Rare	80,000	≈ 100
Exceptional	150,000	>100

STORY OF THE UPPER SLIT DAM

Size

The open check dam has a retention capacity of 10,000 m³ assuming a deposition gradient of 5%, and 18,000 m³ assuming 10% instead. The slit is 5 m wide and 7.5 m high. The spillway built recently atop the slit is 13 m wide and 2 m deep.

Initial design (1986-1987)

The structure was built in 1986-1987 (Fig. 2). It was initially equipped with a steel grill anchored at the bottom in the apron and held at the top by a steel beam.

Fig. 2: The upper slit dam in its first design: a) upstream view of the slit structure in 1986; b) upstream view of the slit and side dykes protected with grouted riprap in 1987; c) downstream view zooming in on the slit and the grill. Note that the downstream face was not protected at that time against erosion during overtopping.

As soon as 1989, the chronic filling of the basin and jamming of the grills by cobbles led to the first adaptation: installing an opening at the base with a clearance of 1 m, and the installation of a horizontal beam to hold the vertical bars.

Debris flow events of 1993

During the debris flow event of Jul. 1st 1993, mud marks demonstrated that the slit dam was filled up to the top. However, the grill did not resist and failed. The top steel beam probably bent under impacts from boulders. The basin underwent self-cleaning with only 5,000 m³ of debris remaining. Although the debris flows reached the banks, indicating full discharge and leaving both debris levees at the sides of the banks and marks against bridge decks, no damage was observed downstream and the canal-bridge over the highway was not overtopped. The functioning was considered satisfactory despite the ruined grill.

Five days later, on Jul. 7th, new debris flows occurred. This time a huge boulder (volume 104 m³) jammed the slit and the basin was completely filled (Fig. 3). This was again considered satisfactory because such a boulder would likely have damaged the downstream lined channel and the canal bridge, or might have obstructed them.

Fig. 3: Second debris flow event of July 7th 1993: a) upstream view of the basin filled up the crest and b) downstream view of the slit jammed boulders. Note the evidences of overtopping and the related marginal erosion.

No more grill on slit dams

After these two events it was concluded that open slit dams are relevant solutions in such sites where trouble occurs (*i*) if the instantaneous discharge is much higher than the fan channel capacity or (*ii*) if huge boulders stop in the channel obstructing them, but not because of the volume of the debris flow events that can be buffered by the confluence. No grills sould be put in such slit dams.

- If debris flows do not transport boulders larger than 3-5 m, the slit dam function is to buffer the debris flow surges, releasing a lower peak discharge more likely to pass through the fan channel.
- If huge boulders are transported, they will likely jam the slit and be trapped, so the function of the slit dam is to trap boulders.

So far, the five debris flows experienced proved that the structures functioned satisfactorily. Slit jamming does happen sometimes, but dozing without jamming prevails (Table 2).

Table 2. Debris flow - slit dam interactions

Date	Excavated Vol. (m^3)	Comment
7/1/1993	5,000	Open check dam filled followed by grill failure, dredging: 5,000 m^3
7/7/1993	15,000	Huge boulder jammed the empty slit.
03/22/2001	4,000	No slit jamming
06/22/2005	18,300	Slit jammed by boulders (Fig. 4)
08/02/2007	4,280	No slit jamming
07/02/2010	14,000	Slit jammed
08/22/2011	6,000	No slit jamming

The second author of this note, Gilles CHARVET, the ONF-RTM officer who designed this dam as well as several others, stresses that in the light of his experience (e.g. bankful discharge was reached several times), he would use a 4-m wide slit rather than 5-m wide slit. Four-meter slits enable trucks to pass through but may become jammed a bit more often. Indeed, the slit dam of the Claret torrent was adjusted to 4 m. The Claret torrent is located nearby and with a similar context than the Saint-Martin torrent except that the confluence has less room, so it was considered relevant that slit jamming and trapping occurs slightly more often.

Additional Adaptations

During the events of 2005, 2010 and 2011, damage was observed on the slit dam apron and the downstream face of the dam. The dam was first protected with grouted riprap to prevent erosion when overtopping occured (compare Fig. 2b and 3b). Secondly, it was equipped with a downstream lined channel, a 7.5 m-high counter dam and 2-m high wings on the spillway (Fig. 5).

CONCLUSIONS

In debris flow torrents, grills set in slit dams might be damaged by huge boulders. Slits are often jammed by boulders about 1.5-2.0 times smaller than slit width. This was acknowledged in existing guidelines (Piton, 2016, p.40), which is consistent with the observations reported in this note. Using single or multiple slits with the proper width is sufficient to trap large boulders and to reduce peak discharge of debris flow surges with small boulders. In addition, single slits that are either equipped with grills or become blocking by jammed boulders will trap the bodies of debris flows, while multiple slits (so called 'debris flow breakers', Rudolf-Miklau and Suda, 2013) are more prone to trap mostly boulders and to partially self-clean the debris flow body composed of gravel and mud.

Fig. 4: Deposit after the debris flows of June, 22nd 2005: a) bouldery deposit nearly filling the basin and b) slit nearly jammed by two large boulders

Fig. 5: Structure in 2020 with wings, lined channel and counter dam: a) upstream view and b) downstream view

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