A PRACTICAL APPROACH TO BRIDGE OBSTRUCTION SCENARIO SIMULATIONS IN DEBRIS FLOW HAZARD MAPPING

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KEY POINTS

- *Bridge clogging is a phenomenon scarcely studied but critical in hazard mapping in mountain areas.*
- *Lacking a rational approach, we propose a practical method for simulating bridge clogging.*
- *The approach can be used with mobile-bed numerical models such as the TRENT2D used in this study.*
- *The application to a test case shows reasonable results compatible with an actual event.*

1 THE HYDRAULIC PROBLEM OF BRIDGES OVER MOUNTAIN STREAMS AFFECTED BY DEBRIS FLOWS

One of the most important hydraulic problems of bridges over mountain streams affected by debris flows or intense sediment transport is the possibility of clogging caused by stony debris. This situation creates a barrier to the flow of the mixture, causing a large deposition upstream of the bridge and a massive overflow. It should be noticed that the situation of a clogged bridge is, in terms of territorial hazard, even worse than a destroyed bridge.

While the clogging caused by wood debris is a topic present in the literature (see e.g., *Gschnitzer et al.,* 2017; *Macchione & Lombardo,* 2021; *Spreitzer et al.,* 2021 among many others) while the clogging caused by stony debris is much less studied. Moreover, the relevant mechanism and conditions of occurrence are still largely unknown. Moreover, this scenario is seldom considered in the design and verification of the hydraulic section of a bridge, leading to a potential underestimation of the debris flow hazard around mountain streams crossed by bridges. In addition, many hydraulic sections of the bridge have been calculated assuming that the peak discharge of debris flow acts as a pure water discharge over a fixed bed.

Figure 1. Consequences of a bridge clogging in the village of Voueces, Ollomont municipality (AO), following the debris flow event of August 2017.

This last approach is largely insufficient and does not guarantee a good level of safety at least for the following reasons:

1. Clogging often occurs after significant sediment deposition in the bridge section.
2. The flow resistance of a debris flow is far larger than the resistance of clear water therefore, at the same flow rate, debris flow depths are larger than pure water depths.
3. While water in a bridge section can flow in a pressure regime, it is highly unlikely (though not impossible) that a debris flow can flow in such a condition but, on the contrary, a clogging could likely happen when the debris-flow free surface is higher than the bottom elevation of the deck.

Pending the development of a rational theory for stony debris clogging, a reasonable practical approach for simulating the effects of bridge obstruction in debris flow simulations aimed at hazard mapping is highly advisable.

2 A PRACTICAL PROCEDURE FOR SIMULATING THE SCENARIO OF A BRIDGE CLOGGING

As mentioned earlier, it is extremely difficult to evaluate if and when a bridge clogging may occur, because this condition depends on many factors that cannot be predicted deterministically.

To address the clogging problem in a numerical simulation, the simple assumption made in this study is that clogging can occur at the instant when the flow reaches a level equal to or slightly above the lower level of the bridge for a reasonable period (on the order of about ten minutes) and, at the same time, that the deposition under the bridge is significant so that the free span has the same order of magnitude as the mixture d_{90}. The time at which this situation occurs is called the *conventional time of possible occlusion*, t_o. From this time onward, the bridge can be considered as a nonerodible zone having an elevation equal to the top of the deck. The nonerodible condition for the bridge area is based on the fact that the bridge deck consists of concrete or a hard surface that commonly is not eroded (bridge collapse is commonly linked to other mechanisms). Furthermore, when the bridge is clogged by a debris flow, the sediment accumulation usually generates an obstruction that can only be removed mechanically (e.g., with an excavator).

In this work, we have implemented this approach by using the TRENT2D (*Armanini et al.*, 2009) model that, in its updated version (*Rosatti & Zugliani*, 2015; *Zugliani & Rosatti*, 2016), can deal with both mobile bed conditions and nonerodible bed conditions. Since we do not yet have a model capable of automatically setting the scenario, it is necessary to proceed “manually”, dividing the overall event simulation into two separate simulations, carried out in cascade. The detailed procedure required to evaluate an obstruction scenario is as follows:

1. A whole “standard” simulation, namely a mobile-bed, debris-flow simulation in which the bridge is neglected, is performed.
2. The time plot of the free surface at the bridge cross-section where clogging may occur is analysed.
3. If the conventional conditions for occlusion, described above, are reached, then the t_o instant can be identified.
4. A new simulation is then prepared, in which the initial elevations of the computational domain are set equal to the elevation of the bottom reached at the t_o instant in the previous simulation. The elevations in the proximity of the bridge are set equal to the upper level of the deck.
5. In the zones with limited erodible thicknesses, the initial values of the new simulation are set equal to the sum of the erodible thicknesses of the standard simulation and the values of excavations and deposits that occurred up to the t_o instant. A null erodible thickness is imposed on the bridge area, making it nonerodible.
6. The hydrograph of the second simulation is that of the related standard simulation between the instant t_o and the end of the event.

The overall simulation is then given by the succession of the standard simulation, between the initial instant and the instant t_o, and the simulation with obstruction, between t_o and the final instant of the hydrograph.

3 APPLICATION OF THE PROCEDURE TO THE VOUECES VILLAGE CASE

The procedure described in the previous section has been applied to a test case, i.e., the case of the village of Voueces (AO) to test whether the results that can be obtained in such a way can be reasonably employed in a hazard mapping work. As a forcing condition, we have considered a hydrograph with a return period equal to 100 years. Moreover, to understand the importance of a mobile-bed approach compared with the fixed-bed one, a fixed bed water simulation, in which the forcing hydrograph has been set equal to the mixture hydrograph used in the mobile-bed simulations, was carried out without considering the presence of the bridge.

Figure 2(a) presents the comparison of the maximum flooding area obtained with the mobile-bed approach without the presence of the bridge (i.e., “standard” simulation) and with the obstruction scenario described in section 2. Instead, figure 2(b) presents the comparison of the maximum flooding area obtained with the mobile bed approach with the obstruction scenario and with the fixed-bed simulation as defined previously.

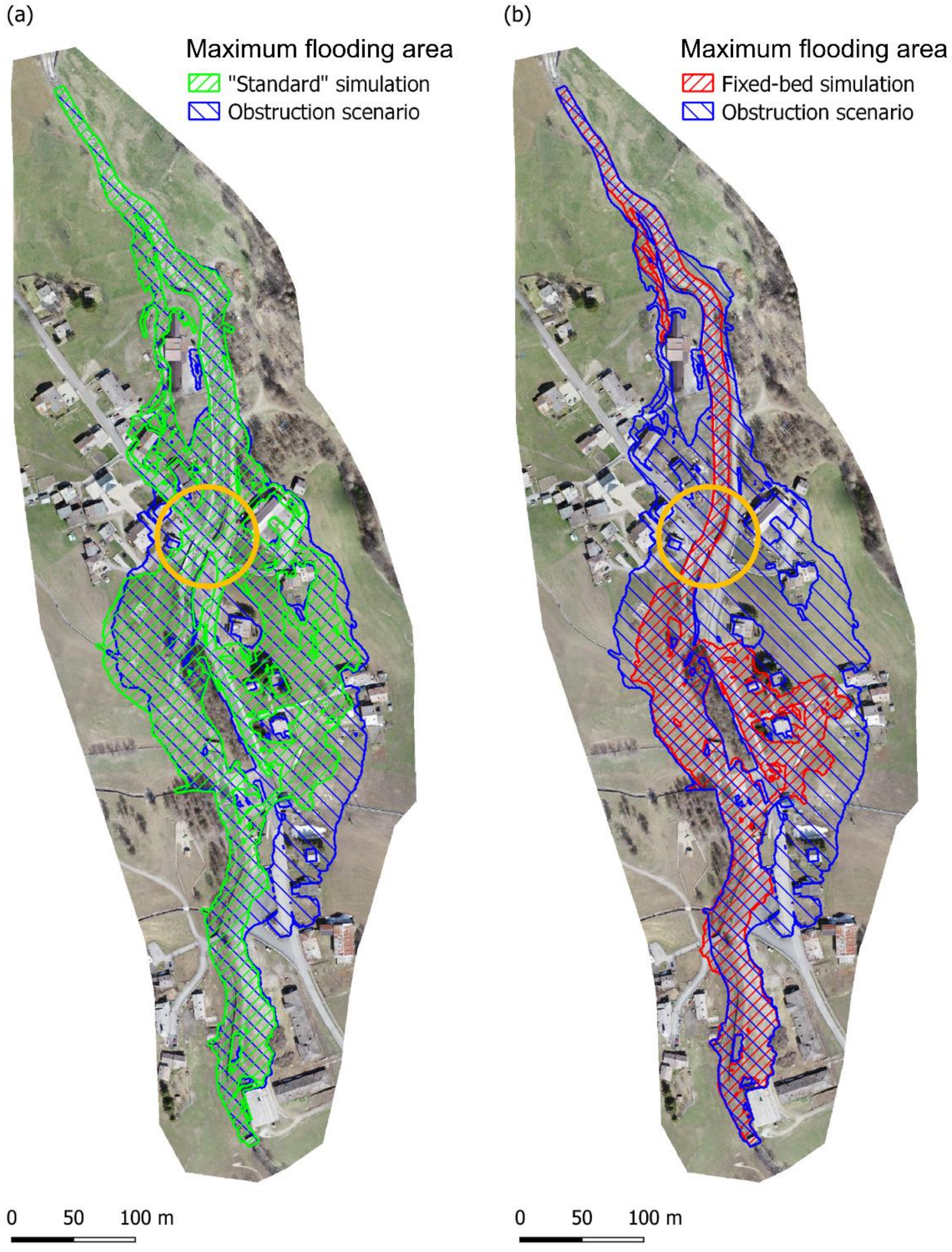

Figure 2. Comparison of maximum flooding area obtained with “standard” simulation, obstruction scenario and fixed-bed simulation. The orange circle highlights the position of the bridge. For the meaning of the simulations refer to the text.

The effect of the bridge clogging leads to a larger inundated area (62000 m^2) than the standard case (50000 m^2) even if, in this specific case, it is not striking (24% increase) because of the large deposition phenomenon occurring, in any case, in the bridge area caused by a significant decrease of bed slope in this zone. Conversely, the results obtained with the pure-liquid, fixed-bed assumption are considerably different since, in this case, the maximum discharge does not overtop the banks and the inundated area is half the case of clogging (30000 m^2).

Finally, the comparison of these results with the event that occurred in August 2017 (not reported for brevity) shows that even though the hydrological forcing of this event is rather different from that of the synthetic hydrograph with a return period equal to 100 years and the DTM used in the simulations (current state) is somewhat different from the pre-event condition, the extension of the inundated area and the deposition depths are reasonably similar.

4 CONCLUSIONS

Bridge clogging due to debris-flow events is an important phenomenon that affects mountain areas. Even if preliminary, the results of this work suggest that:

1. The widely used approach of designing and verifying bridge sections by using a fixed-bed water flow model leads to a significant underestimation of the hazard associated with debris flows.
2. Lacking a rational theory for debris clogging and pending the development of a better methodology, the simple procedure we have proposed for simulating the bridge clogging scenario seems to be a reasonable and effective approach.

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REFERENCES

Armanini, A., Fraccarollo, L. & Rosatti, G. Two-dimensional simulation of debris flows in erodible channels, Computers and Geosciences, 2009, 35(5), 993–1006.

Macchione, F. & Lombardo, M. Roughness-Based Method for Simulating Hydraulic Consequences of Both Woody Debris Clogging and Breakage at Bridges in Basin-Scale Flood Modeling, Water Resources Research, 2021, 57(12).

Gschnitzer, T., Gems, B., Mazzorana, B. & Aufleger, M. Towards a robust assessment of bridge clogging processes in flood risk management, Geomorphology, 2017, 279.

Spreitzer, G., Tunnicliffe, J. & Friedrich, H. Effects of large wood (LW) blockage on bedload connectivity in the presence of a hydraulic structure, Ecological Engineering, 2021, 161.

Rosatti, G. & Zugliani, D. Modelling the transition between fixed and mobile bed conditions in two-phase free-surface flows: The Composite Riemann Problem and its numerical solution, Journal of Computational Physics, 2015, 285, 226–250.

Zugliani, D. & Rosatti, G. A new Osher Riemann solver for shallow water flow over fixed or mobile bed, Proceedings of the 4th European Congress of the IAHR, 2016.