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One-dimensional mathematical modelling of debris flow impact on open-check dams

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Abstract

The impact of debris flows on open-check dams is modeled as a Riemann problem in a rectangular cross-section channel with downstream dry state. Under the assumption that the energy is conserved through the structure, this special Riemann problem exhibits four different solution configurations. It is shown that the solution always exists, but there are ranges of the initial conditions and of the geometric characteristics for which the solution is not unique. Two different criteria for the disambiguation of the solution are proposed, and it is shown that these criteria are in agreement. The exact solutions presented can be used as internal boundary conditions in one-dimensional numerical models for the propagation of the debris-flow in river channels and narrow valleys, or as a numeric benchmark.

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Keywords: Debris-flow; Open-check dam; Impact; Riemann problem; Analytic solution; Hydraulic hysteresis.

1. Introduction

The open-check dams are frequently classified with reference to their shape and structure, or with reference to their objective and function[1]. Among their objectives, it is possible to consider not only the control of the sediment discharge in mountain streams (stabilization of the longitudinal channel bed profile, consolidation of river banks,

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sediment retention, sorting of sediments), but also the mitigation of the debris flow propagation effects[1,2]. During the impact of the debris flow, these structures act in several manners. First, they block large diameter boulders and driftwood (mechanical trapping function). Second, they reduce the stream width, forcing the formation of horizontal and vertical axis eddies immediately upstream, with the passage from supercritical to subcritical flow conditions (energy loss function), and this loss of energy upstream reduces the flow destructivity power. As additional effect, the deceleration of the flow induces the deposition of the small diameter sediments transported (hydraulic trapping function). Among the alternative structures, it is possible to consider slit- and sectional open-check dams. Schematically, the slit-check dams (Fig. 1a) consist of a channel constriction, where the stream width passes from b to b_0 (with $b_0 < b$) through a single opening. Conversely, sectional check-dams with fins or piles (Fig. 1b) consist of a flow obstruction where the stream width is reduced from b to b_0 through multiple openings.

Numerous experimental studies are available for these structures[2-4], but the numerical modeling is often required to improve the design of complex systems for the mitigation of debris flows. At the present, sophisticated two- and three-dimensional[5] numerical models for the simulation of debris flow propagation are available. Nonetheless, these models are computationally demanding, and cheaper alternatives must be used where possible, or when the examination of numerous flow propagation scenarios is needed. In one-dimensional modeling of debris flow propagation[6-8], which is appropriate in the case of channelized flow, the correct treatment of internal and external boundary conditions is a critical issue[9-11], and poor implementation of these boundary conditions may influence adversely the quality of numeric results.

In this paper, a special Riemann problem[12] is used to model the impact of debris flow on slit- and sectional check-dams, in order to supply an appropriate internal boundary condition in one-dimensional mathematical models of debris flow propagation, where the open-check dam is modelled as a width rapid transition, through which the energy is conserved[1,2, 13]. The remainder of the paper is organized as follows. First, the mathematical position of the problem is made, then the analytic solution of the special Riemann problem is supplied. Finally, it is shown that there are initial conditions for which this solution is not unique, and two different disambiguation criteria are discussed.

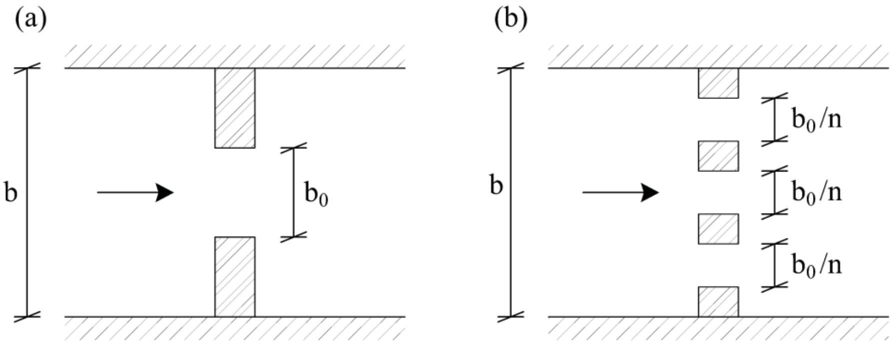

Fig. 1. Examples of open check-dams layout: (a) slit-check dam; (b) sectional check-dam with piles.

2. Analytic solution of the debris-flow impact mathematical model

In this section, the impact of the debris flow on open-check dams is modeled as the analytic solution of a special Riemann problem for the Shallow-water Equations. First, the curves used to construct the graphical solution of the Riemann problem are introduced, and then the solution is supplied.

2.1. Position of the impact model

Assuming horizontal frictionless channel with uniform rectangular cross-section, the classic Saint-Venant Equations[14] can be rewritten as: