Finite Volume Non-hydrostatic Pressure Model for the Simulation of Landslides

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Abstract

A Finite Volume (FV) numerical scheme previously designed for the hydrostatic Shallow Water Equations (SWE) is extended to compute non-hydrostatic pressure (NHP) in order to simulate dispersive waves. These waves are usually generated by landslides and are of importance in coastal alarm systems. The model is validated in 1D comparing with laboratory measurements and the results highlight the importance of including the NHP terms in the model to achieve a good agreement between numerical and experimental results.

Methodology

Mathematical model

The set of mass and momentum conservation equations is used to describe the flow [1]:

$$\frac{\partial h}{\partial t} + \frac{\partial (hu)}{\partial x} = 0$$

$$\frac{\partial (hu)}{\partial t} + \frac{\partial}{\partial x}\left(hu^2 + \frac{1}{2}gh^2\right) + gh\frac{\partial z_b}{\partial x} = \underbrace{-\frac{1}{2}\left(h\frac{\partial p_{nh}}{\partial x} + p_{nh}\frac{\partial (h+2z_b)}{\partial x}\right)}_{\text{Non-hydrostatic terms}}$$

$$\frac{\partial w}{\partial t} + \frac{\partial (wu)}{\partial x} = \frac{p_{nh}}{h}$$

$$h\frac{\partial (hu)}{\partial x} + 2hw + (hu)\frac{\partial}{\partial x}(h+2z_b) = 0$$

This formulation allows to recover the hydrostatic flow configuration assuming $p_{nh} = 0$. When a NHP model is nevertheless required, a fractional step procedure is applied to solve explicitly the hydrostatic part and then, solve the Poisson equation for NHP with an implicit model [2]. The novelty in this work lies in the explicit part, performed with a first order FV Roe-type scheme, that ensures an energy balance and proposes a correct treatment of the wet-dry fronts [3].

Validation through experimental data

Available data of an experimental setup consisting on a channel with a wave generating piston are used to validate the results [4]. The experiment is focused on the generation of controlled dispersive waves that normally appear when a landslide occurs. A sketch of the experimental layout can be seen in Figure 1. Several observation points distributed along the channel registered the temporal variations of water depth.

During the experiments, several cases were designed on a different initial water depth. The cases shown here are performed with $h_0 = 25$ cm (see Figure 1).

In Figure 2, the comparison of the experimental data and the numerical simulations is displayed at the points 1-5 shown in Figure 1. The simulations are carried out with both hydrostatic and non-hydrostatic models. Both computations are performed with two different grids (400 and 1200 cells) in order to asses mesh sensitivity.

Conclusions

In the light of the results, the importance of a NHP model is crucial for the simulation of dispersive waves. Particularly, the high order harmonics generated by the piston are well captured by the NHP model, in contrast to what happens with the SWE model.

Once the use of the NHP model is justified, the validation shows a good agreement between numerical and experimental results, confirming not only the good performance of the system, but also the good implementation of the wet/dry fronts. However, some further analysis must be done to understand the wave reflection at the downstream wall and temporal delays in results from t = 500 s.

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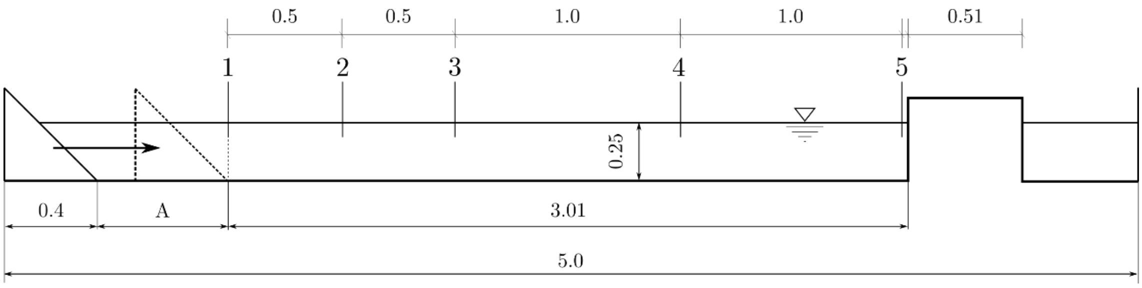

Figure 1: Sketch of the test case layout.

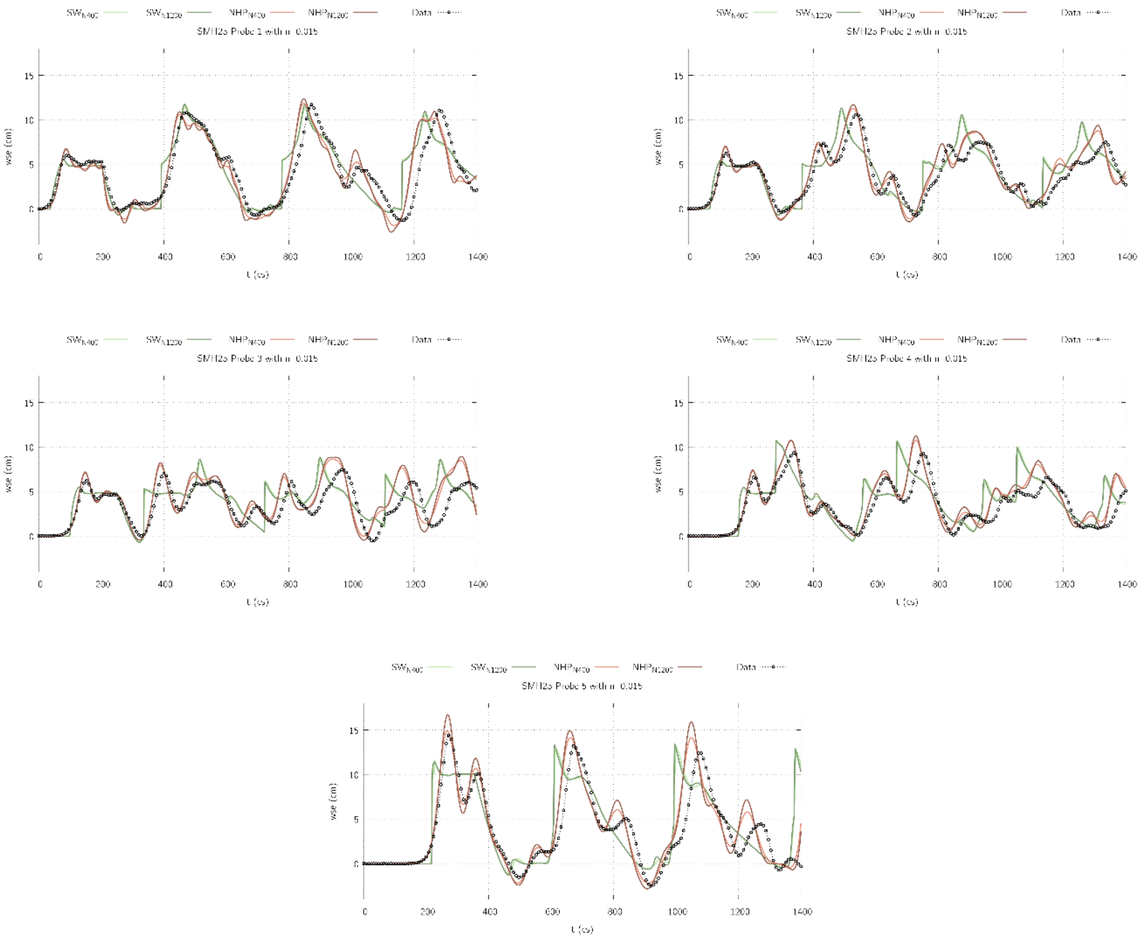

Figure 2: Time evolution of water surface elevation in experimental data (black), for the SWE (green) and for the NHP model (red).