

Comparison of coupled and weakly coupled HLLC based finite-volume schemes for dam-break flows on mobile bed

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ABSTRACT

We hereby compare the performance of a weakly coupled finite-volume model against a fully coupled one on a two-dimensional dam-break test case with movable bed. Both models consider bed-load only and are HLLC based, but the weakly coupled one uses an upwind scheme for the sediment fluxes. It appears that the weakly coupled model is far better at predicting maximum deposition and erosion amplitudes and does not suffer from excessive diffusion regarding bed evolution.

1. Introduction

Although dam-break numerical simulations usually show good agreement with experimental data regarding water level evolution, the accuracy of most models in predicting bed level evolution is more arguable. Several approaches exist, but provided that the bed is only subject to bed-load, a finite-volume model implementing the Saint-Venant-Exner (SVE) equations makes a strong candidate for dam-break simulations in 2D with erodible bed. Several flux schemes can then be used to calculate fluxes at the interfaces of the cells, among which the lateralized HLLC scheme that can be put forward for its simplicity (Soares-Frazão and Zech, 2010). Nevertheless, the coupling between the hydrodynamics and the bed evolution makes this scheme inappropriate in both 1D and 2D because of excessive bed material diffusion (Goutière et al., 2008; Franzini and Soares-Frazão, 2018). For that reason, we propose to decouple the shallow-water equations from the Exner one and to apply an upwind scheme, based on a numerical characteristic, to compute the sediment flux at the interfaces (Juez et al. 2014).

2. Methods

For the full description of both models, please refer to Meurice and Soares-Frazão (to be submitted). For the sake of brevity, only the major final difference between both models is indeed hereunder discussed.

2.1. Coupled Model (CM)

In the CM, the unit solid discharge fluxes at the interfaces are calculated thanks to the HLLC scheme:

$$q_{s,n}^* = \frac{\lambda_s^+ q_{s,n,L} - \lambda_s^- q_{s,n,R} + \lambda_s^+ \lambda_s^- (z_{b,R} - z_{b,L})}{\lambda_s^+ - \lambda_s^-} \quad (1)$$

where $q_{s,n}^*$ – normal component of the unit solid discharge flux at the interface between a left cell L and a right one R [m^2s^{-1}], λ_s^+ – the fastest characteristic related to sediments [ms^{-1}], λ_s^- – the slowest characteristic related to sediments [ms^{-1}], $q_{s,n,L}$ – the normal component of the unit solid discharge computed for cell L [m^2s^{-1}], $q_{s,n,R}$ – the normal component of the unit solid discharge computed for cell R [m^2s^{-1}], $z_{b,R}$ – the bed level of cell R [m], $z_{b,L}$ – the bed level of cell L [m].

A look at Eq. (1) makes us understand that its last term will eventually lead to a flat bed or at least to a different slope than the equilibrium one.

2.2. Weakly Coupled Model (WCM)

In this model, the HLLC scheme is no longer applied to calculate $q_{s,n}^*$. We indeed use an upwind scheme related to a numerical characteristic $\tilde{\lambda}_{s,n}$ defined to guarantee consistency between the integral of the exact solution of the Exner equation and the integral of the solution linearized locally at the interface (Juez et al. 2014). The unit solid discharge flux at the interface is then given by:

$$q_{s,n}^* = \begin{cases} q_{s,n,L} & \text{if } \tilde{\lambda}_{s,n} \geq 0 \\ q_{s,n,R} & \text{if } \tilde{\lambda}_{s,n} < 0 \end{cases} \quad (2)$$

with

$$\tilde{\lambda}_{s,n} = \frac{1}{1 - \epsilon_0} \frac{\Delta q_{s,n}}{\Delta z_b'}, \quad \Delta z_b' = \begin{cases} \Delta z_b & \text{if } \Delta z_b \geq d_{50} \\ -S_f ds & \text{if } \Delta z_b < d_{50} \end{cases} \quad (3a, 3b)$$

where ϵ_0 – the bed porosity [–], $\Delta z_b = z_{b,R} - z_{b,L}$ – the bed level difference between cells R and L [m], d_{50} – the representative diameter of the grains [m], S_f – the friction slope of the upstream cell [–], ds – the distance between the centers of cells R and L [m] (Juez et al., 2014).

Although the hydrodynamical fluxes are still calculated with the HLLC scheme, $q_{s,n}^*$ is now no longer subject to excessive diffusion.

3. Results and discussion

Different test cases with available experimental data were used to compare the coupled and weakly coupled approaches. Results are illustrated here for the dam-break flow in a wide floodplain over mobile bed (Soares-Frazão et al., 2012). Results for the dry bed case (Fig. 1) show that the WCM is far better at predicting maximum deposition along the edges of the flume and maximum erosion just after the enlargement.

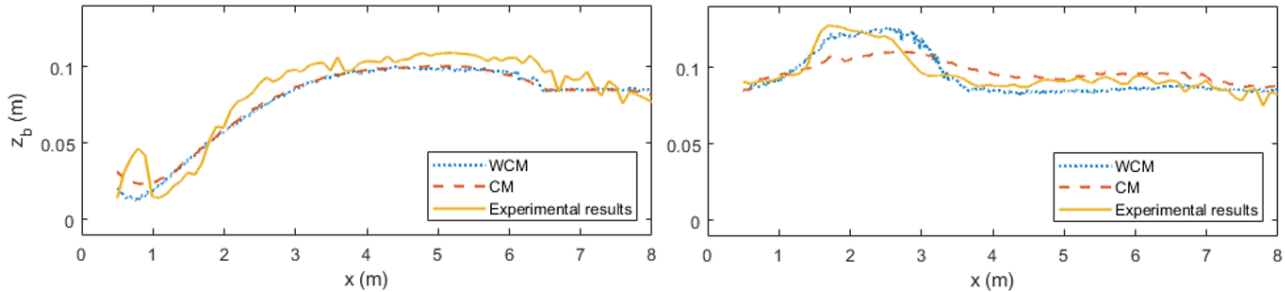


Fig. 1. Models comparisons at predicting maximum erosion (left) and deposition (right).

4. Conclusions

A finite-volume weakly coupled model inspired by Juez et al. (2014) was tested with a combination of a lateralized HLLC flux scheme for the hydrodynamics and an upwind scheme for the bed evolution. Its performance on a 2D dam-break on movable bed was compared with a coupled SVE model using the lateralized HLLC flux scheme only (Soares-Frazão and Zech, 2010). Besides avoiding an excessive bed material diffusion, it appears that the WCM better performs than the CM at assessing maximum deposition and erosion. This WCM thus constitutes an efficient model for 2D dam-breaks or other highly transient flows if bedload only is considered.

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