DEVELOPMENT AND APPLICATION OF A 2D FREE-SURFACE SOLVER FOR MODELING LANDSLIDE-GENERATED WAVES IN THE GENERAL FRAMEWORK OF DAM-BREAK FLOOD WAVE PROPAGATION (ABSTRACT)

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INTRODUCTION

Floods mitigation, inundation mapping, floodplain management and prediction of waves generated by landslides are issues of continuously growing interest for a wide range of practitioners. A specific topic in which the HACH team has been involved for several years is the analysis of dam break risks. Efficient modeling of this type of highly unsteady flows, possibly including regime changes (mobile hydraulic jumps and discontinuous wave fronts), remains a challenging task for hydro-engineers and modellers. The present abstract provides a description of an effective numerical model (WOLF) to be used as strategic tool in the analysis of dam-break related flows, both upstream and downstream of the structure. The code solves the shallow water equations with an efficient original numerical technique.
Classical computations of waves induced by landslides is based on simple graphs, giving a direct relation between the landslide characteristics and the subsequent wave height. The downstream propagation is thus computed afterwards in an uncoupled way, neglecting major interactions between the hydrodynamic phenomena and the landslide.
On the other hand, the research undertaken is devoted to achieve a completely integrated modelling of the hydrodynamic processes induced after a landslide, including the flow in the reservoir, the potential break of the overtopped dam and the downstream wave propagation.

The software package WOLF has been developed for almost ten years in the Division of Applied Hydrodynamics and Hydraulic Constructions (HACH) at the University of Liege. WOLF includes a completely integrated set of numerical models for simulating any unsteady free surface flow regime (physically-based and spatially distributed hydrology, 1D, 2D, sediment transport, air entrainment, in cartesian or curvilinear coordinates in the vertical plane …) as well as optimisation algorithms.
A user-friendly interface, completely developed by the HACH, makes the pre- and post-processing operations very convenient and straightforward to control. The grid generator deals with 2D structured and unstructured meshes. The interface enhances post-processing capabilities, including 2D and 3D views as well as animations.
The computation core has reached now a high degree of reliability. Its stability, robustness and accuracy have been widely highlighted. Indeed the validation of the model has been performed continuously by comparisons with analytical solutions, field and laboratory measurements available in the literature or collected in the Hydraulic Laboratories in Liege. The HACH team has also been involved in intensive validation programs in the framework of European research projects (e.g. Concerted Action on DAM-break modelling, Investigation of

Extreme Flood and Uncertainty). Other validation works have already been published in several previous papers.

NUMERICAL MODEL DESCRIPTION

In the shallow-water approach (SWE) the only assumption states that velocities normal to a main flow direction are smaller than those in the main flow path. As a consequence the pressure field is found to be almost hydrostatic everywhere.

Conceptual model

The SWE model simulates any steady or unsteady situation, possibly taking into consideration air transport or sediment-laden flows. The large majority of flows occurring in rivers can reasonably be seen as shallow and characterized by relatively small vertical velocity components everywhere except in the vicinity of some singularities. This confirms the relevance of the SWE approach, which is in addition coupled to a turbulence model based on the Prandtl mixing length concept. The modified SWE model developed in the context of the present research provides the possibility of imposing surface forcing in the three directions of the space with a time dependence or not. An imposition of a time dependent topography is also operational in the model.

Algorithmic implementation

A finite volume scheme is used in all models to ensure exact mass conservativity, which is a prerequisite for handling properly discontinuous solutions like moving hydraulic jumps. As a consequence no assumption is required regarding to the smoothness of the fields. If needed, an automatic mesh refinement tool is available to boost the convergence rate towards highly accurate steady-state solutions.

In addition to the well-established Roe scheme, an original FVS is presented for space discretization of the complete set of equations. The stability of this second order upwind scheme has been demonstrated through a theoretical study of the mathematical system as well as a von Neumann stability analysis. Much care has been taken to handle correctly the source terms representing topography gradients.

The models allow the user to specify any inflow discharge as an upstream boundary condition. The downstream boundary condition can be a free surface elevation, a water height, a Froude number or even no specified condition if the outflow regime is supercritical.

An implicit pseudo-time integration scheme, suitable for solving non-transient problems, is implemented in the SWE model. This technique allows to use much larger time steps than those acceptable for an explicit time integration. On the other hand the resolution procedure is more intricate. A Newton method is exploited to solve the large non-linear system. The successive linearized systems are solved with the powerful GMRES algorithm, which is advantageously coupled to a preconditioner. For this purpose an Incomplete LU decomposition is applied. The Switched Evolution-Relaxation technique by Van Leer has been used to continuously optimise the time step.

The resolution procedure represents a very challenging step because of the complexity of a cost-effective evaluation of the Jacobian matrix. WOLF performs this job effectively, by storing only non-zero elements and their location in the large sparse matrix.

A second 2D model for hydrodynamics, simplified according to the *diffusive* assumption, may be used for rapidly generating initial flow fields for the complete model in case of steady flows.

A fully objective calibration of friction coefficients is possible automatically with the WOLF's optimisation tool, which is based on the innovative Genetic Algorithms.

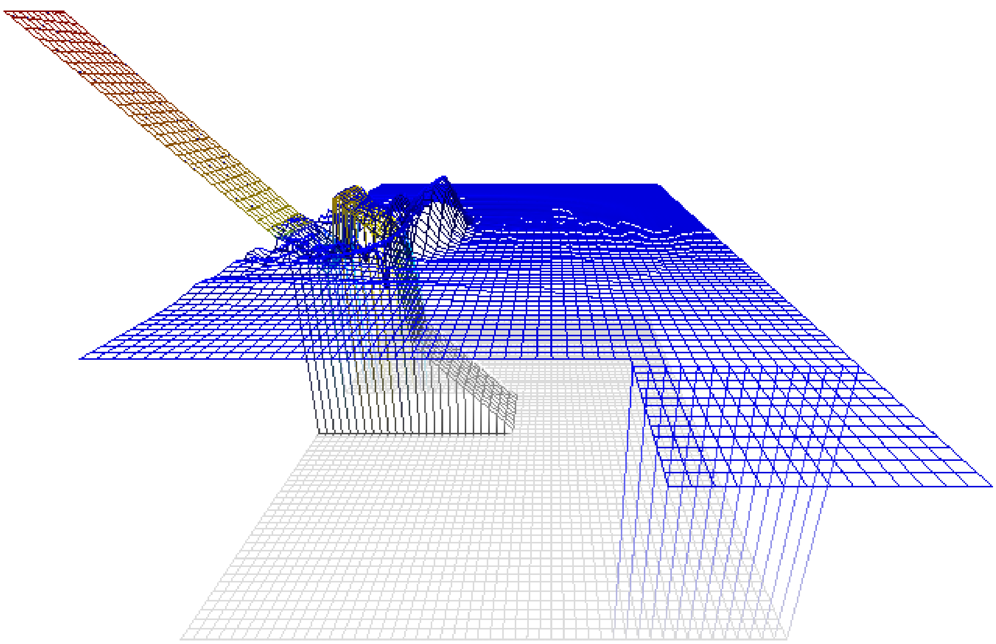
LANDSLIDE EXPERIMENT

A landslide physical model has been developed to study the features of induced waves submerging hydraulic structures. The idealized reservoir has a rectangular shape with a spillway and an inclined plane that allows to drop concrete blocks into the reservoir. Resistive measure gauges provided us with wave height time dependent results. An original speedometer gave the velocity of the concrete block during its acceleration down to the water level but also during the impact and its falling in the water.

A large set of experiments was performed including different water levels and falling heights. It constitutes the bases for the analysis of the phenomenom we observed in this case and allows a reliable comparison for assessing the numerical modelling we achieved with the modified SWE model. The resulting adaptations we developed in the numerical model are focused on two major points: an evolutive topography based on the real velocity of the sliding volume and an imposition of an original forcing on the front face of the block.

CONCLUSION

The great amount of data collected allowed a good comprehension of the phenomenon. The numerical modelling we developed finally gives satisfaction in regards to the extreme flow conditions. Besides the first results suggest further developments both for the numerical and the experimental models (granular landslide, other configuration of the landslide's geometry,…).



3D view of a numerical simulation of landslide-generated waves.