Some Benchmark Simulations for Flash Flood Modelling

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Flash Floods

Rapid flooding due to

- heavy rain in a watershed
- meltwater of snow and ice
- failure of a protection structure

Time scale: few hours maximum
Flood Warning

- Early Warning
- Flood Routing
Flood Modelling

- Urban Planning
- Identification of flood risk zones
- Flood risk maps
- Improve hazard mitigation actions
- Enhance emergency planning
- Flood prediction
- Communication of flood risk to the public
Shallow Water Equations

SWE

Saint-Venant Equations

- Volume Conservation
  \[ \frac{\partial \eta}{\partial t} + \nabla \cdot (Hu) = 0 \]

- Momentum Conservation
  \[ \frac{\partial u}{\partial t} + (u \cdot \nabla)u + g\nabla H - F = 0 \]

with total water depth \( H \), water height above reference height \( \eta \), velocity vector \( u \), acceleration and due to gravity \( g \) and vector of outer forces \( F \)
Extension

Hydraulics with friction on the walls

\[ \frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} \cdot \nabla) \mathbf{u} + g \nabla H + g \eta n^2 \frac{|\mathbf{u}|}{\eta^{4/3}} \mathbf{u} - \mathbf{F} = 0 \]

with Manning coefficient $n$

(Brufau & García-Navarro 2000, Duran 2015)

Implemented in COMSOL Multiphysics as physics mode by Schlegel (2012)
Benchmarking

- against analytical solutions
- against numerical results from other codes, accepted by the scientific community
1D Dambreak Problem Set-up

Initial condition: dam at position $x_0$
high water level upstream (left), low water level downstream (right)
at simulation time zero the dam disappears
1D Dambreak Analytical solution
Straight Forward Model

100 Elements, without stabilization
Effects of Stabilization

Inconsistent
• artificial viscosity
Consistent
• shock wave capturing

100 Elements, comparison of
• consistent (with markers) and
• inconsistent (gray) stabilization
Effect of Element Order

100 Elements, comparison of
- linear (with markers)
- quadratic (gray) element
Effect of backwater height

Analytical solution

\[ Y^3 - 9XY^2 + 16XY^2 - X(X+8)Y + X^3 = 0 \]
for \( X = h_0 / h_1 \) and \( Y = h_2 / h_1 \)

Numerical solution

- 400 elements
- consistent stabilization
Effect of Adaptive Meshing

Comparison of
- Linear fixed elements
- Quadratic fixed elements
- Adaptive meshing
2D Dambreak Problem Set-up

Left: initial state
Right: water table change after dam break
Straight Forward Model

Front propagation after dam break (2D) along the main diagonal at selected time instances, no stabilization
Effects of Stabilization

Comparison of
• consistent (with markers) and
• inconsistent (gray) stabilization
Effect of Mesh Refinement

comparison of results with consistent stabilization with two mesh refinements:
  • reference mesh (gray),
  • refined mesh (spacing 0.01 m (black)
  • double refined mesh (spacing 0.005 m)
It is a 2D problem with a rectangular obstacle located in the backwater. The model was treated experimentally and modelled numerically by several groups within the IMPACT project. The experiment is documented by Soares Fracão et al. (2004) and Soares Fracão et al. (2011).
COMSOL Model

- Model set-up: There is a no-flow no-slip condition along walls. The Manning friction coefficient is $n = 0.01$.
- Elements: 2. order
- Stabilization: consistent
- Adaptive meshing: max. 4 refinements
Front, Early Time

Front propagation after dam break (2D) with obstacle after 0.66 s
Front, Intermediate Time

Front propagation after dam break (2D) with obstacle after 2 s
Front, Long Time

Front propagation after dam break (2D) with obstacle after 3 s
Summary & Conclusions

1. For the 1D and 2D classical benchmarks we checked numerically computed shock waves using the analytical solution. Straight forward discretization leads to spurious oscillations. Inconsistent stabilization supresses the oscillations, but introduces a numerical viscosity error. Quadratic elements produce more accurate solutions than linear elements.
Summary & Conclusions

2. For the usual parameter range, both in 1D and 2D, adaptive meshing techniques lead to accurate solutions utilizing much less computational resources than simulations on fixed meshes. We observed reduction by factors:

- model size: 8 times smaller
- execution time: 20 times faster
References


- IMPACT (2001), http://www.impact-project.net/impact_project_overview.htm


Acknowledgements

- TRC
- COMSOL Multiphysics
- German Univ. of Technology in Oman
Outlook

International Symposium on Flash Floods in Wadi Systems

ISFF3
December 5-7, 2017
Muscat, Sultanate of Oman
German University of Technology in Oman