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Some Benchmark Simulations for Flash Flood Modelling

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Flash Floods

www.pinterest.com

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

Photoblog.nbcnews.com

Flood Modelling

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Houston, Texas, Sep. 2, 2017

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

Shallow Water Equations

SWE

Saint-Venant Equations

- Volume Conservation

$$\frac{\partial \eta}{\partial t} + \nabla \cdot \left(H\mathbf{u} \right) = 0$$

- Momentum Conservation

$$\frac{\partial \mathbf{u}}{\partial t} + \left(\mathbf{u} \cdot \nabla \right) \mathbf{u} + g \nabla H - \mathbf{F} = 0$$

with with total water depth H, water height above reference height η, velocity vector $\mathbf{u}$, acceleration and due to gravity g and vector of outer forces $\mathbf{F}$

Extension

Hydraulics with friction on the walls

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

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

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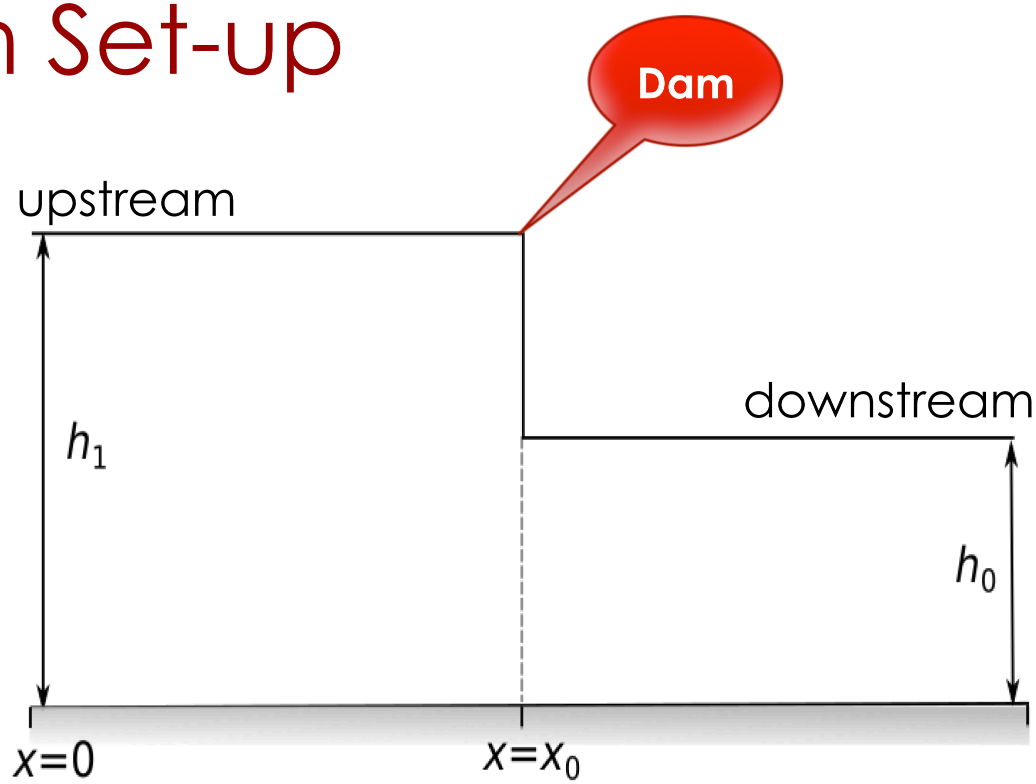

Initial condition: dam at position x_0
high water level upstream (left), low water level downstream (right)
at simulation time zero the dam disappears

1D Dambreak
Analytical solution

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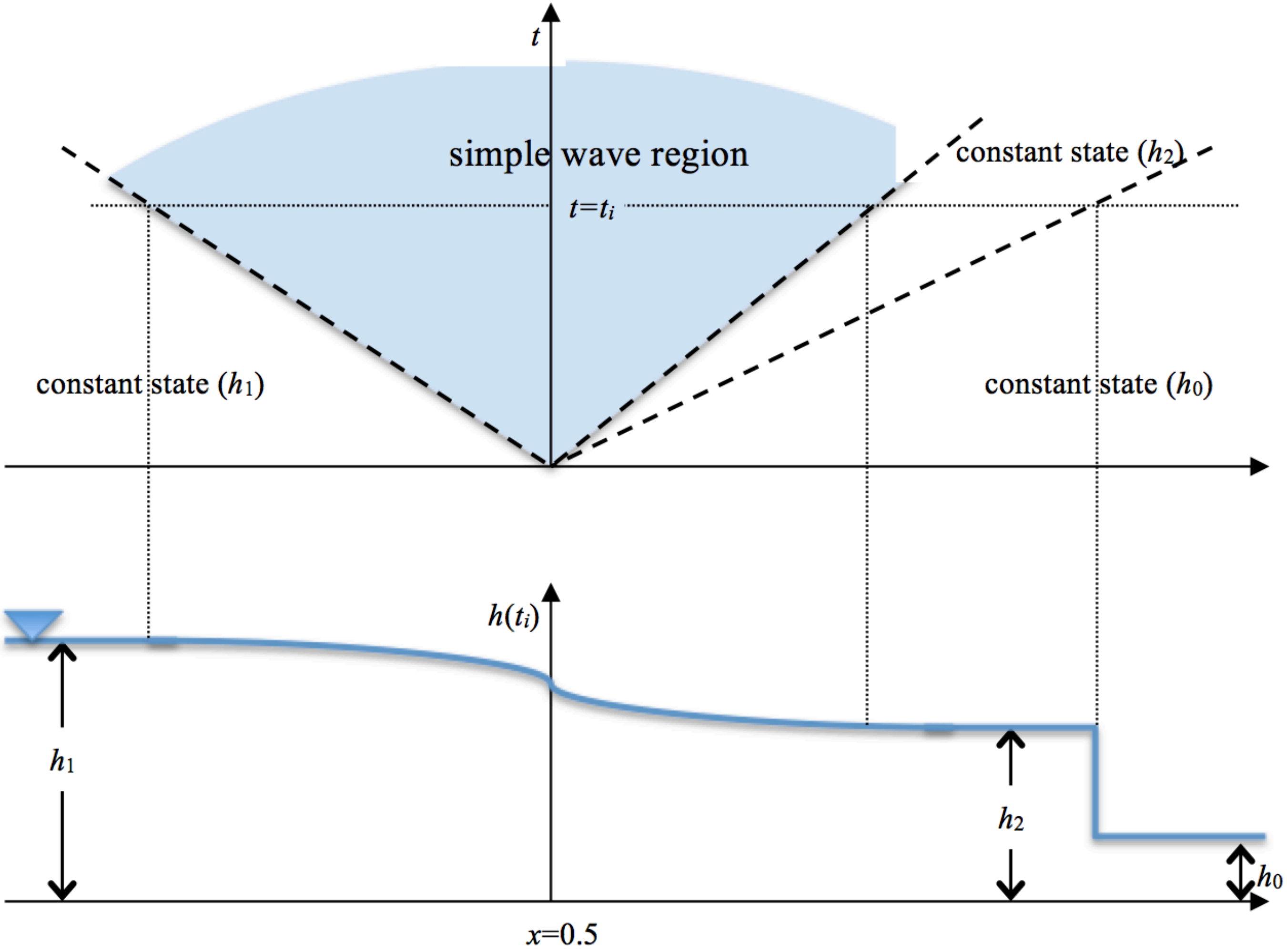

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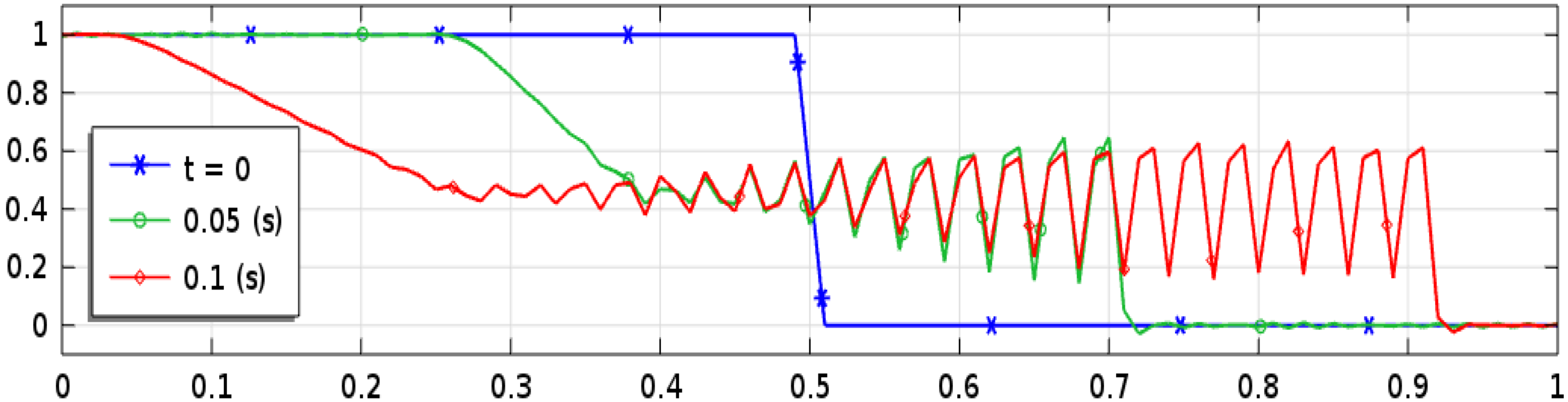
Straight Forward Model

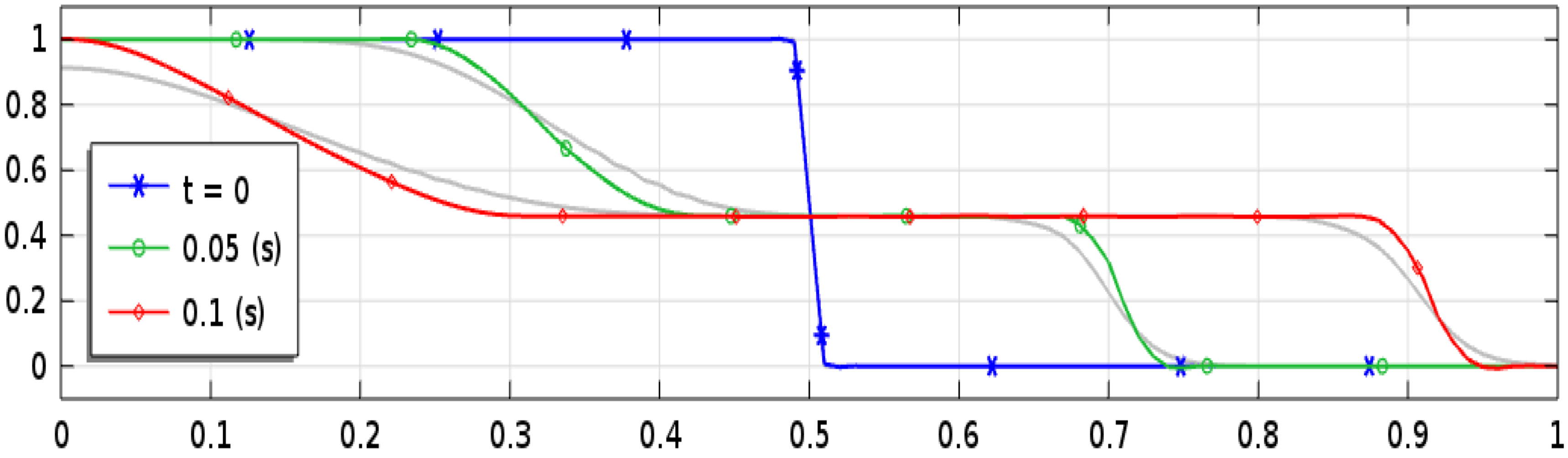


1oo Elements, without stabilization

Effects of Stabilization

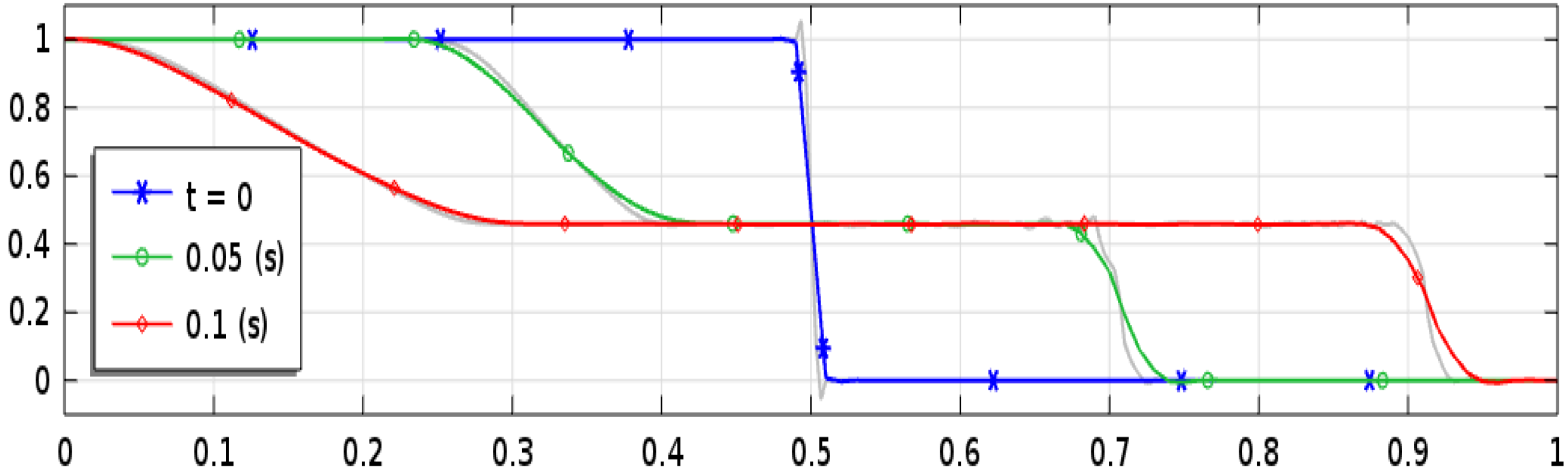
Inconsistent
- artificial viscosity

Consistent
- shock wave capturing



1oo Elements, comparison of
- consistent (with markers) and
- inconsistent (gray) stabilization

Effect of Element Order



1oo Elements, comparison of

- linear (with markers)
- quadratic (gray) element

Effect of backwater height

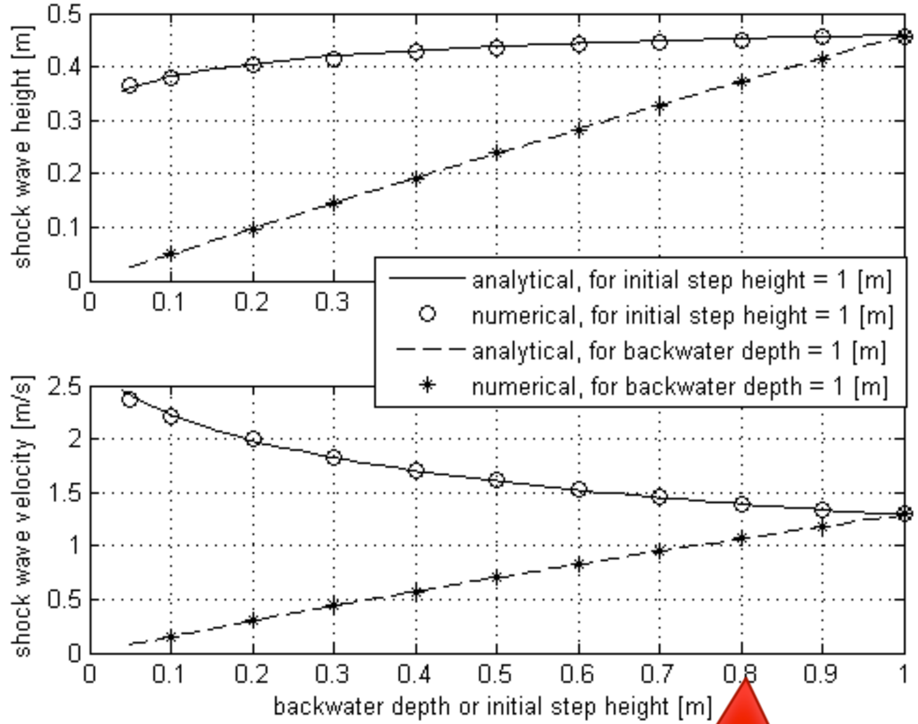
Analytical solution

$$Y^3 - 9XY^2 + 16XY^{3/2} - X(X+8)Y + X^3 = 0$$

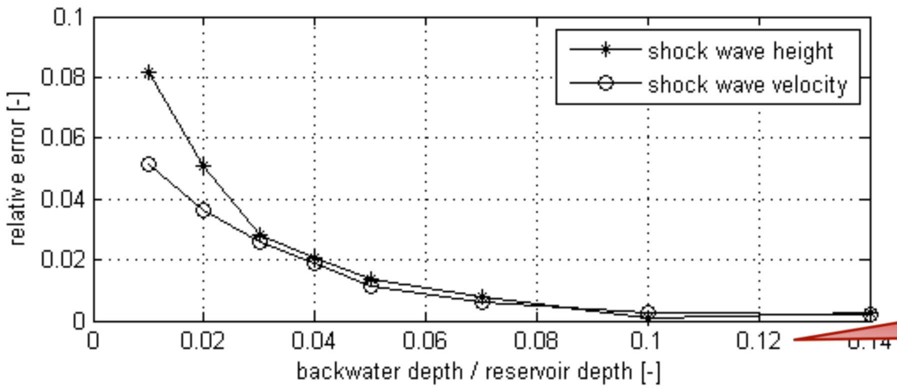
for $X = h_0 / h_1$ and $Y = h_2 / h_1$

Numerical solution

- 400 elements
- consistent stabilization

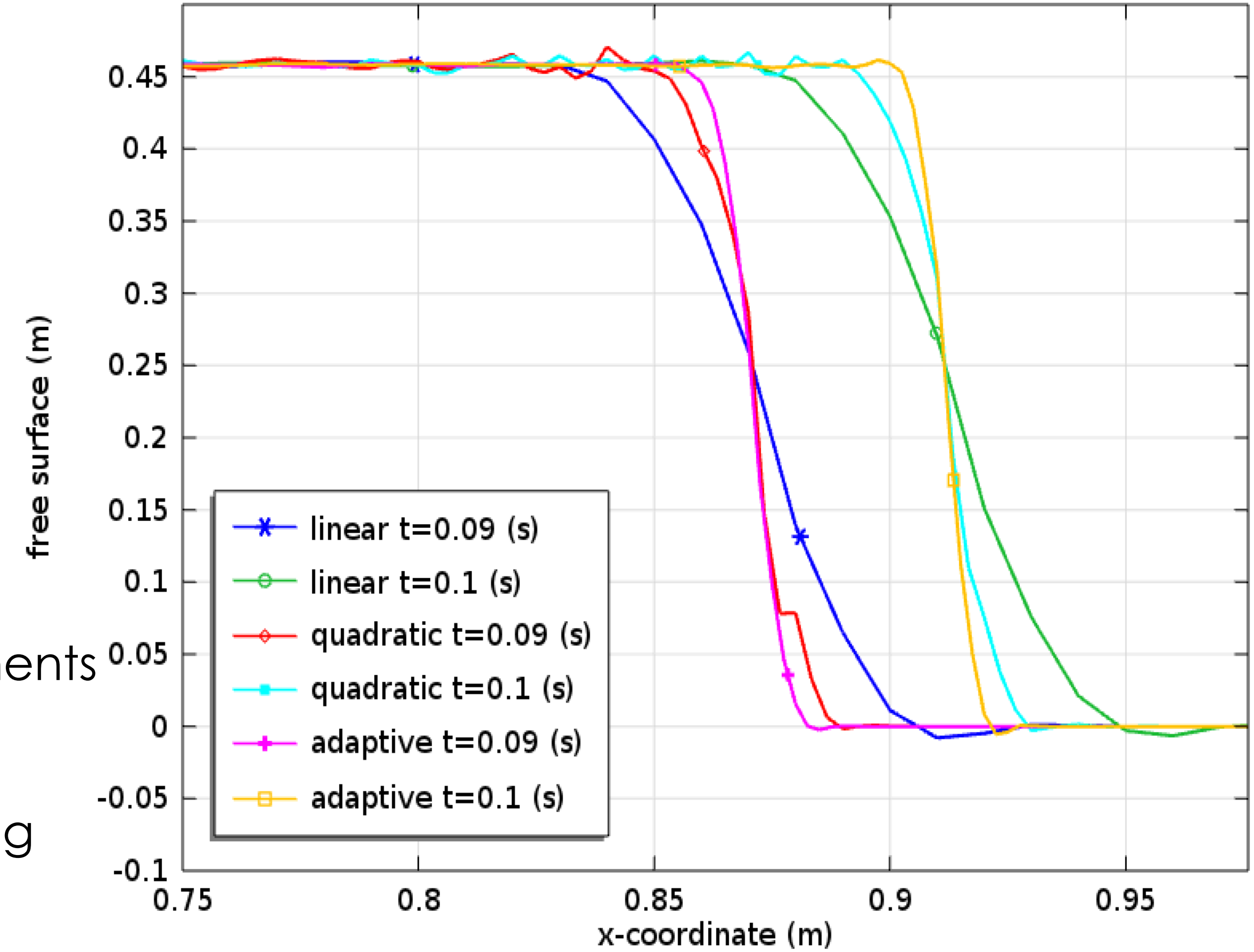


High values



Low values

Effect of Adaptive Meshing



Comparison of

- Linear fixed elements
- Quadratic fixed elements
- Adaptive meshing

2D Dambreak
Problem Set-up

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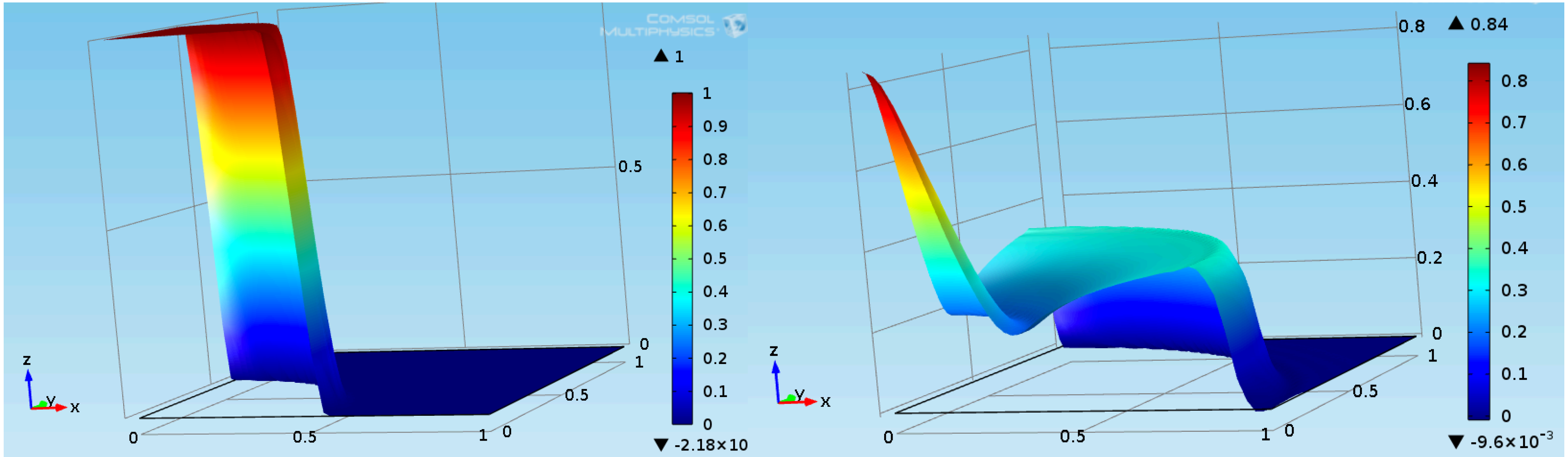
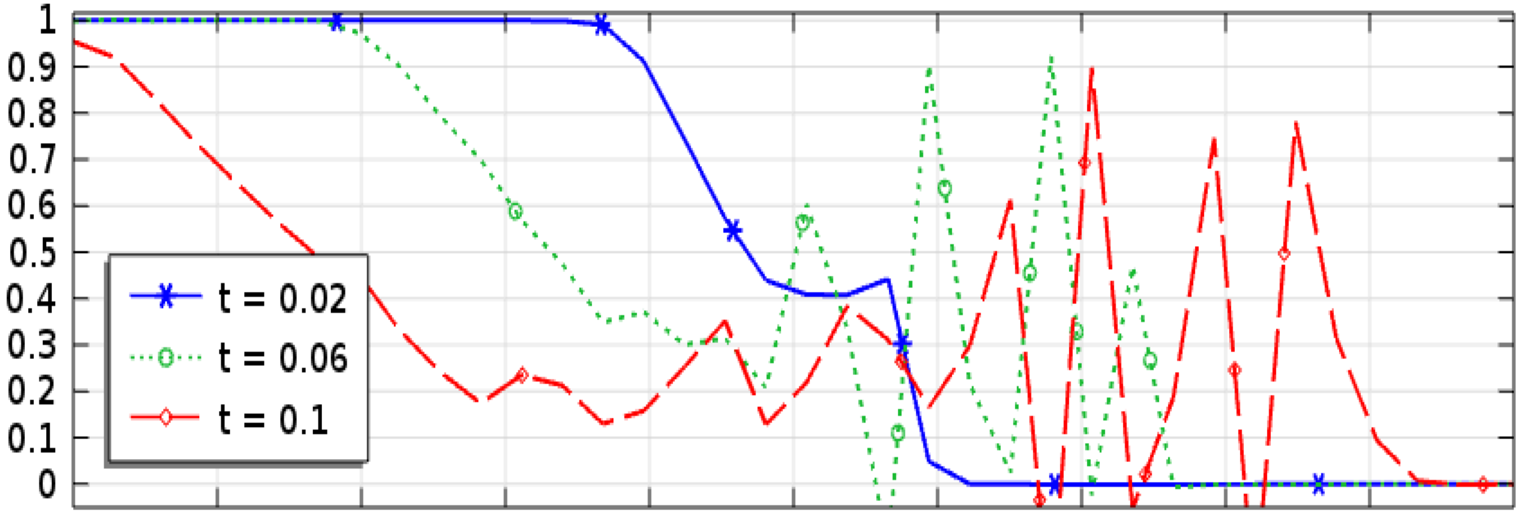


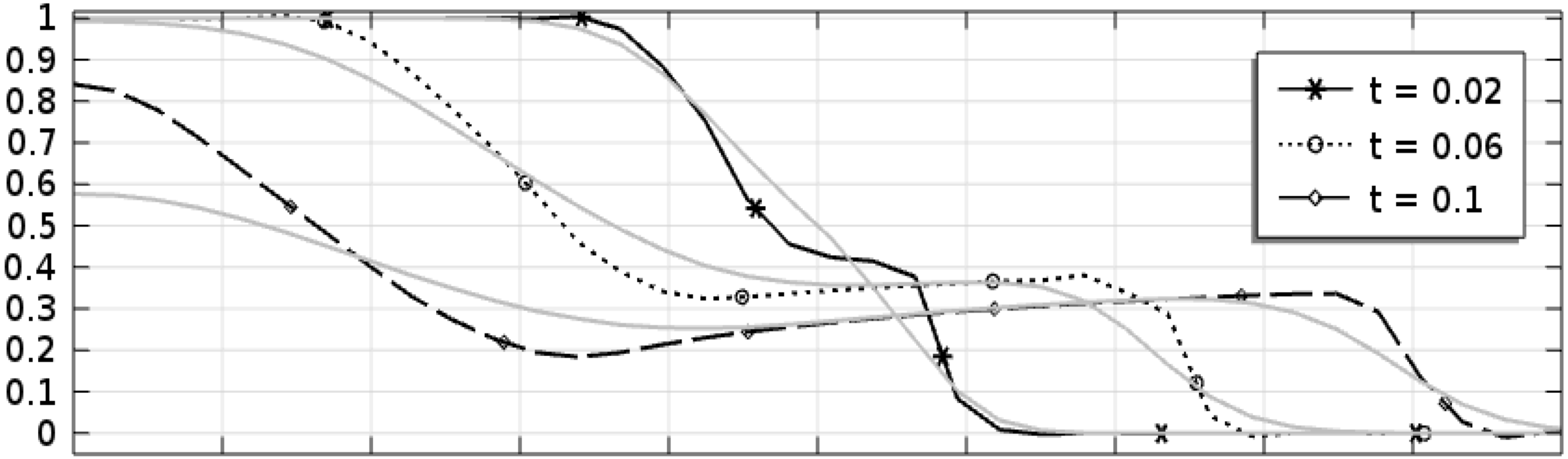
Left: initial state
Right: water table change after dam break

Straight Forward Model



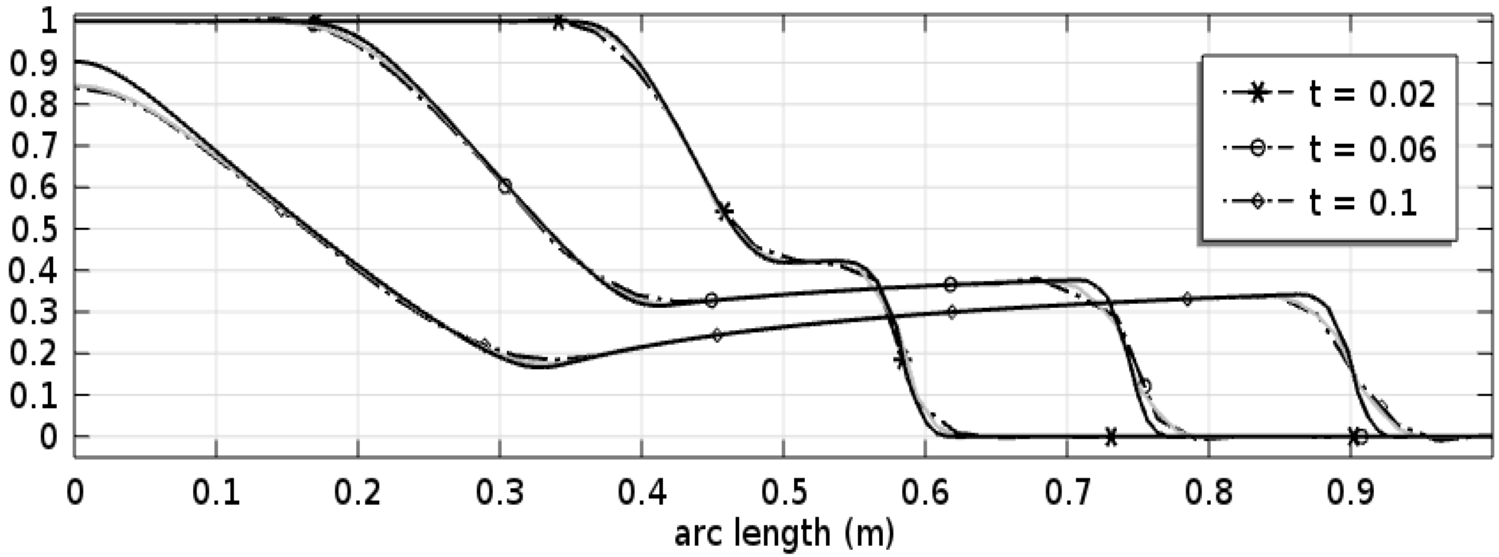
Front propagation after dam break (2D) along the main diagonal at selected time instances , no stabilization

Effects of Stabilization



Comparison of
- consistent (with markers) and
- inconsistent (gray) stabilization

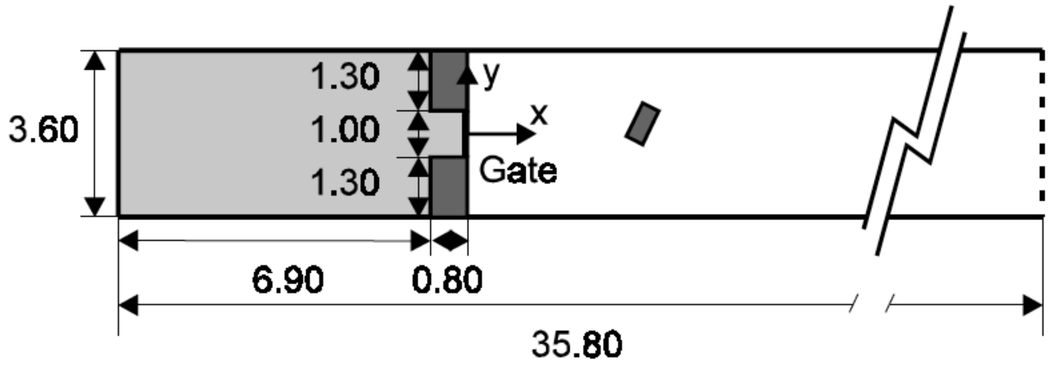
Effect of Mesh Refinement



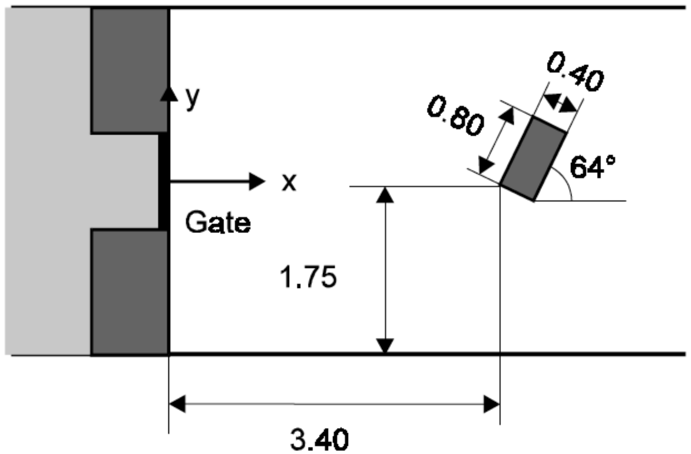
comparison of results with consistent stabilization with two mesh refinements:

- reference mesh (gray),
- refined mesh (spacing 0.01 m (black)
- double refined mesh (spacing 0.005 m)

2D Dambreak with Obstacle Problem Set-up

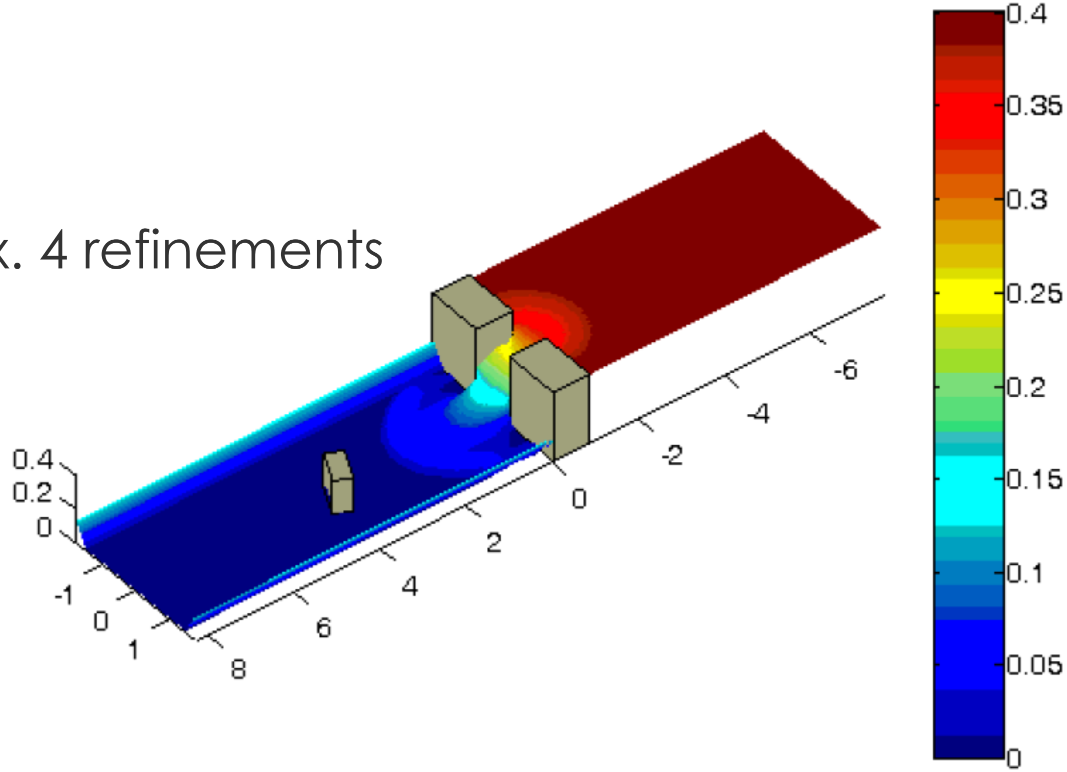


It is a 2D problem with a rectangular obstacle located in the backwater. The model was treated experimentally and modelled numerically by several groups within the IMPACT project. The experiment is documented by Soares Fracão *et al*. (2004) and Soares Fracão *et al*. (2011).

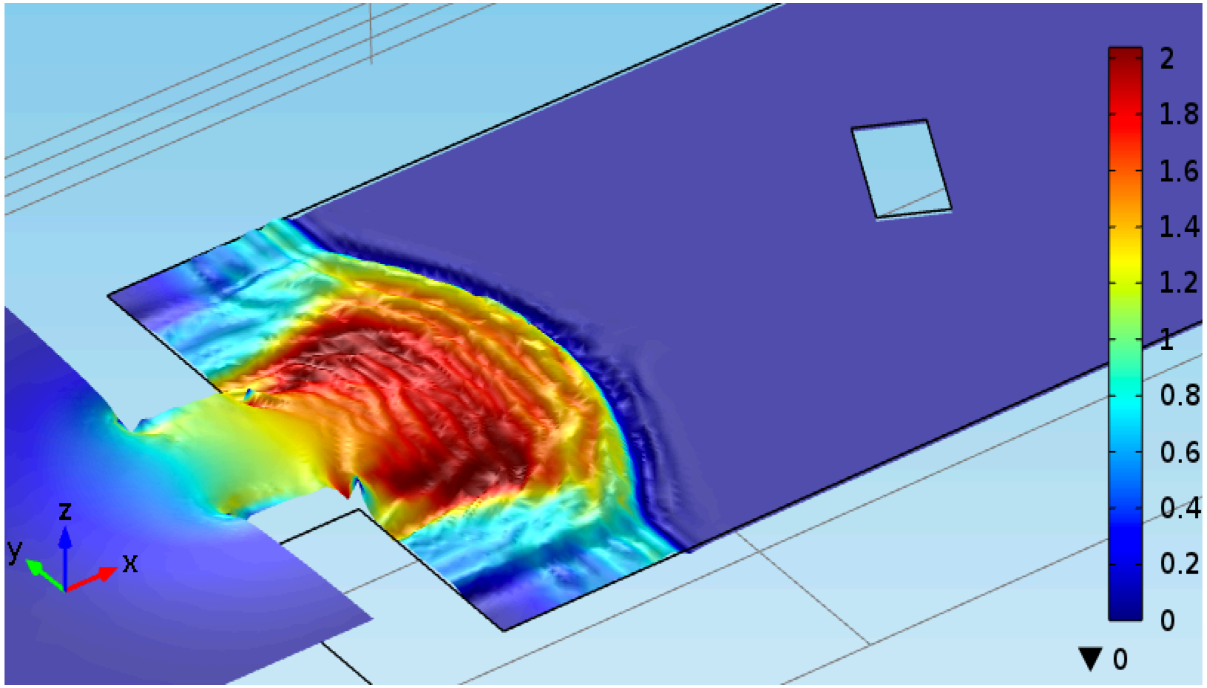


COMSOL Model

- 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

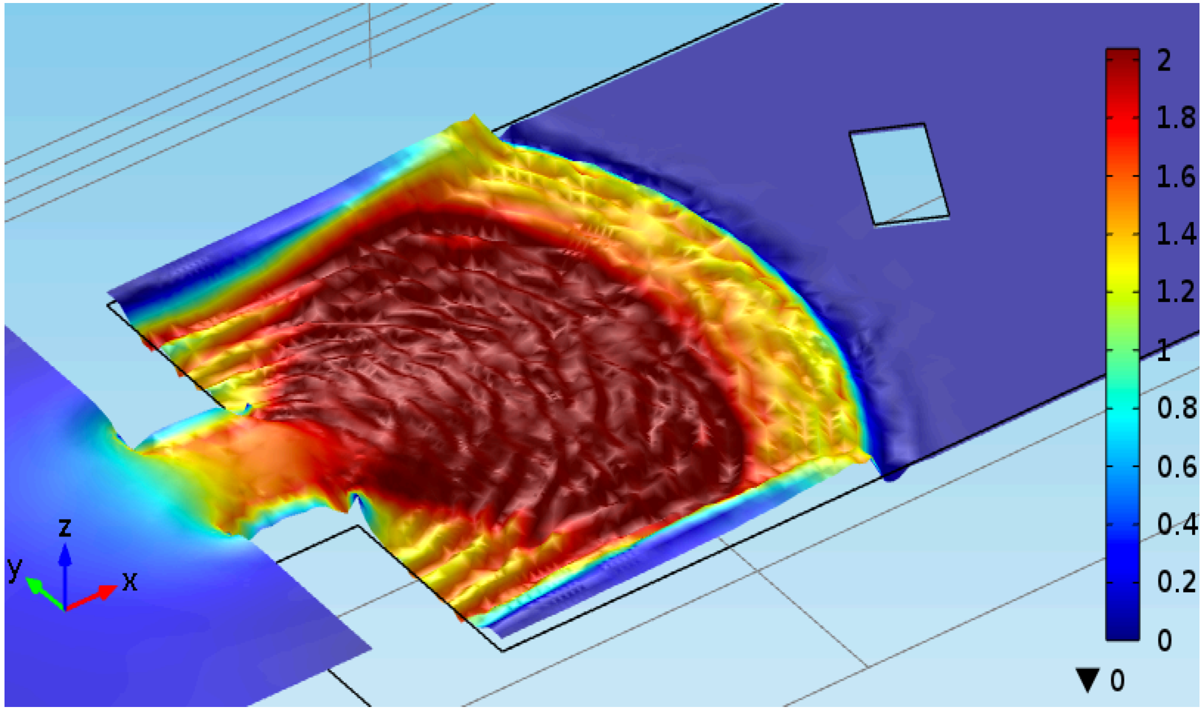


Front, Early Time



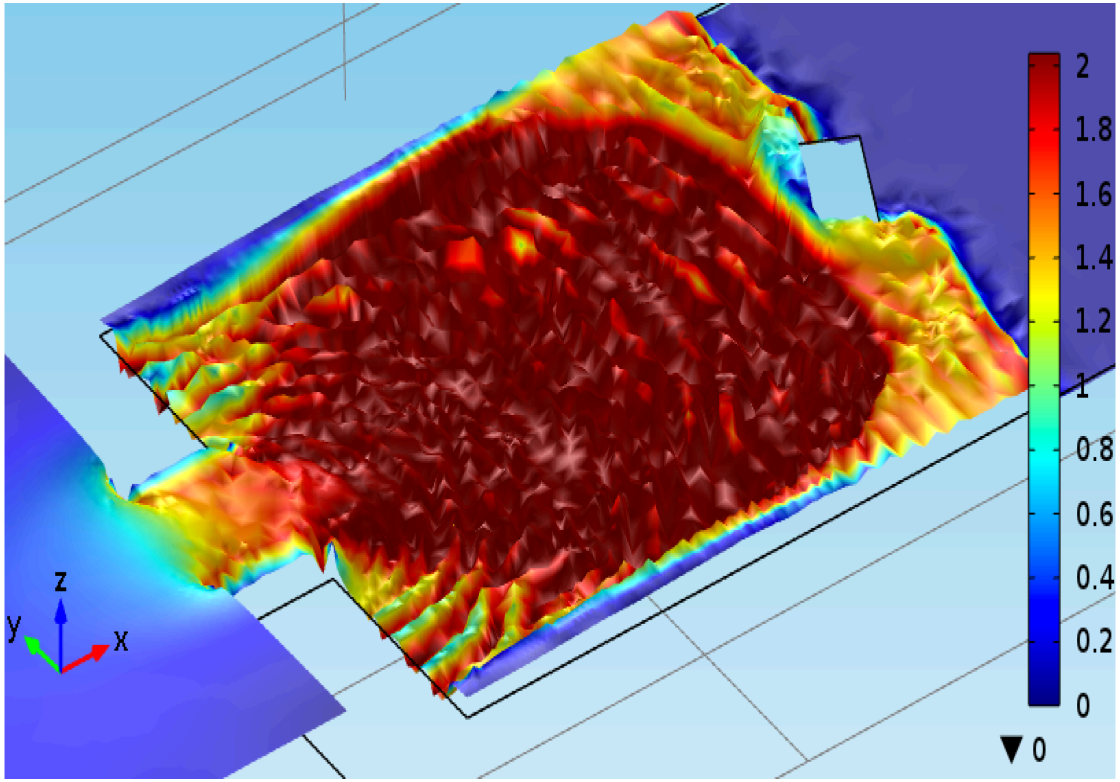
Front propagation after dam break (2D) with obstacle after 0.66 s

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

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Outlook

International Symposium
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in Wadi Systems
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ISFF3

December 5-7, 2017

Muscat, Sultanate of Oman

German University of Technology in Oman