A two-dimensional dam-break flow simulation model for preparing emergency action plans

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Outline

Dams in India

Dam-break modelling

Model verification and validation

EAP for dam-break floods

Conclusions
Dams in India

- Large Dams: 5125
- Importance of Dams
- Lack of funds for maintenance
- Floods due to Dam failure
- EPA for dam-break floods
EAP Components (CWC 2006):

- Notification flowcharts
- Responsibilities
- Emergency identification, evaluation and classification
- Notification procedure
- Preventive action
- Inundation map (from dam-break model)
- Appendices for supporting materials
Infrastructures form a complex network. Failure of an infrastructure may cause failure to other systems.

Failure front, which may be quite different than flood front.

Fig. 1: Inundation map with failure fronts
Available Dam-break Flow Models

- **1D Models**: MIKE 11, HEC-RAS
- **2D Models**: MIKE 21, TUFLOW, CLAWPACKS

Limitations of available models

- Dam-break model with GPU
- Integrated GIS and Dam-break model
Governed Equations

\[
\begin{align*}
\frac{\partial U}{\partial t} + \frac{\partial F(U)}{\partial x} + \frac{\partial G(U)}{\partial y} &= S(x,y,U) \quad (2D \text{ depth-averaged shallow water equation})
\end{align*}
\]

where,

\[
U = (H, \quad q_x, \quad q_y)^T
\]

\[
F = \left( q_x, \quad \frac{q_x^2}{h} + \frac{gh^2}{2}, \quad \frac{q_x q_y}{h} \right)^T
\]

\[
G = \left( q_y, \quad \frac{q_x q_y}{h}, \quad \frac{q_y^2}{h} + \frac{gh^2}{2} \right)^T
\]

\[
S = \left( 0, \quad gh(S_{0x} - S_{f_x}), \quad gh(S_{0y} - S_{f_y}) \right)^T
\]

**Notations**

- **U** = Variable vector
- **F, G** = Convective flux
- **S** = Source term
- **H** = Water depth
- **h** = Water depth
- **z_b** = Channel bed elevation
- **S_{ox}, S_{oy}** = Bed slopes
- **S_{fx}, S_{fy}** = Friction slopes

Fig. 1: Definition sketch
Numerical Solution

- **Time discretization**: Explicit forward Euler scheme
- **Space Discretization**: Finite volume method
- **Convective flux**: HLLC Riemann solver
- **Source terms**: Friction by semi-implicit and bed slope by well-balanced method
- **Accuracy**: Second-order accurate in space and first-order in time
- **Stability criteria**: Courant condition
- **Computational grid**: Unstructured quadrilateral
Model Validation
Partial Dam-break in Laboratory Flume

Experiment: Fraccarolo and Toro (1995)

- Reservoir: 1 m long and 2 m wide
- Floodplain: 3 m long and 2 m wide
- Gate width: 0.4 m
- Quadrilaterals: 6141

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Table 1: Locations of stage Gauges

Fig. 2: Computational mesh for the partial dam-break test and gauge locations
Fig. 3: Computed and measured depth evolutions at different gauges
Dam-break flow in a Converging-Diverging Channel

**Experiment: Bellos et al. (1992)**

- Length: 20.7 m, Slope: 0.006
- Manning’s $n = 0.012 \text{ m}^{-1/3}\text{s}$
- Gate located at: 8.5 m
- Initial Water level in the reservoir: 0.3 m
- Quadrilateral Cells: 5047

**Fig. 4:** Geometry of the converging-diverging channel
Fig. 5: Converging-diverging section of the computational grid for the dam-break test case by Bellos et. al. (1992)

Fig. 6: Computed and measured flow depth comparisons at: (a) $x = 0.0$ m (b) $x = 4.5$ m and (c) $x = 18.5$ m
Laboratory Dam-break over a Triangular Hump

Experiment: CADAM Project, EU

- Manning’s n: 0.0125 m$^{-1/3}$s$^{-1}$
- Square Cells: 0.1 m × 0.1m
- Dam located at: 15.5 m

**Fig. 7:** Definition sketch of the experimental set up for dam break over a triangular hump (distorted scale)
Fig. 8: Depth profiles at gauges: (a) G4, (b) G10, (c) G11 and (d) G20
Fig. 9: Sardis lake partial dam-break simulation for 72 hrs on 30 m DEM
EAP for Dam-break Floods

Flood at a dam site:

- Sudden uncontrolled release
- Excessive controlled release
- Release caused by damage to or failure of the dam

EAP Preparation:

- Low-hazard dams
- Significant-hazard dams
- High-hazard dams
The model can generate following information for EAP preparation:

- The extent of the flooded area
- Spatial distribution of flood depth at various times
- Spatial distribution of flood velocities in two horizontal directions at different times
- Flood arrival time at each point of the computational domain
- Duration of the flood at each point of the computational domain
The Right Model for Preparing EAP

- The computation time should be reasonable – GPU implementation
- Computational grid – DEM may be better choice
- Smooth flow of data – model integration with GIS
- Visualization – GIS and Google Earth
- Low-cost EAP preparation – web based remote computations
• Minimal hydrology or modeling skills required by user
• Minimal user input
  ✓ Dam location and height
  ✓ Reservoir maximum volume
  ✓ Bridge locations
  ✓ Reservoir bathymetry or outflow hydrograph not required
  ✓ No expensive workstation or GIS software required at the user end
• Simple dam break analysis through remote server
  ✓ Total and instantaneous dam break
  ✓ Flood maximum depths and arrival time results
• Transfer of selective maps to the user for EAP preparation
Conclusions

- A 2D dam-break model is presented
- The model uses finite volume method and the HLLC Riemann solver
- The model is validated against a number of experimental observations
- The model can be used for preparing inundation maps for different dam-break scenarios
- The inundation maps can be used to prepare EAP for dam-break floods
Thank You

Comments and Suggestions