Test-case number 17: Dam-break flows on dry and wet surfaces (PN, PA, PE)

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1 Practical significance and interest of the test-case

The dam-break problem has been widely studied in the literature by many different experimental, theoretical and numerical methods (see Harlow & Welch (1965) for example). Under the assumptions of isothermal and incompressible flow, two configurations are considered in this test-case (see figure 1):

- Problem 17.a: the dam-break on a wet ground where initially, a water layer of height h_l and length $L/2$ is considered, to the right hand side whereas we consider a water layer of height h_r on the other side. The dam is supposed to break instantaneously and we want to predict the free surface evolutions, h_i, and the hydrodynamics at every instant after the dam breaks.
- Problem 17.b: the dam-break on a dry ground with identical characteristics, except that a dry bottom exists downstream from the dam ($h_r = 0$).

The two test cases are very interesting because they allow to validate the numerical simulations compared to experimental data and unsteady theoretical solutions. The problem emphasizes the influence of the gravity, the surface tension and the viscosity. Shock and rarefaction waves appear during the wave breaking over the downstream water layer. In certain cases, it is observed the developmental of a water jet leading to free surface shearing, stretching and droplet ejection. The strong deformations of the interface and the unsteady character of the flow confer on the two test cases a reference point of view to validate front tracking methods as well as numerical approximation of the two-phase Navier-Stokes equations.

2 Definitions and physical model description

Dam-break simulations in two dimensions are considered here. The two problems 17.a and 17.b were studied experimentally by Martin & Moyce (1952) on the dry case and P.K. Stansby & Barnes (1998) for the two cases. Accurate experimental data are available in these previous references. The dam-break flow admits in addition analytical solutions under the hydrostatic pressure and perfect fluid assumptions (see the works of S. Vincent & Caltagirone, 2001, Vincent, 1999, for example), through the Saint-Venant or Shallow-Water model and the non-linear characteristic theory (see figures 2 and 3). The theoretical solution of test case 17.a is given by the following procedure where the notations are defined in figure 2.

- from $x = -L/2$ to OA (OA is the curve $x = -\sqrt{gh_l}t$), the analytical solution is $u_m = 0$ and $h_i = h_r$.

- from OA to OB (OB is the curve $x = h_s t$), we have $u = (\frac{2}{3}\sqrt{gh_l} + \frac{2}{3}\frac{x}{t})$ and $h_i = \dfrac{(\frac{2}{3}\sqrt{gh_l} - \frac{x}{3t})^2}{g}$.
- from OB to OS (OS corresponds to the curve $x = st$, where s is the shock velocity), the free surface h_s and the velocity u_s, as well as s, are obtained by solving the following system

$$u_s + 2\sqrt{gh_s} - 2\sqrt{gh_l} = 0 \quad (1)$$

$$s(h_r - h_s) + h_s u_s = 0 \quad (2)$$

$$s h_s u_s - (\frac{gh_r^2}{2}) + (\frac{(h_s u_s)^2}{h_s} + \frac{gh_s^2}{2}) = 0 \quad (3)$$

- from OS to $x = L/2$, the solution is $u_m = 0$ and $h_i = h_r$

where u_m is the mean velocity of the flow deduced from the Saint-Venant equations, t is time and x is the horizontal space coordinate.

For test case 17.b, we obtain,

- from $x = -L/2$ to OA, a steady state corresponding to the initial state is obtained. OA is the curve $x = -\sqrt{gh_l}t$. The analytical solution is $u_m = 0$ and $h_i = h_l$
- from OA to OS, a rarefaction wave develops containing a sonic point at $x = 0$. OS is the curve $x = 2\sqrt{gh_l}t$. The theoretical solution is $u_m = (\frac{2}{3}\sqrt{gh_l} + \frac{2}{3}\frac{x}{t})$ and $h_i = \dfrac{(\frac{2}{3}\sqrt{gh_l} - \frac{x}{3t})^2}{g}$
- from OS to $x = L/2$, the steady initial state is kept. The solution is then $u_m = 0$ and $h_i = h_r$

Considering the celerity of the surface waves $c_g = \sqrt{gh_l}$ as the reference velocity of the problem, we define the following dimensionless Froude and Reynolds numbers :

- $Fr = \dfrac{u_0}{c_g}$,
- $Re = \dfrac{\rho_l (h_l - h_r) c_g}{\mu_l}$.

where u_0 is a characteristic velocity of the flow defined as the averaged velocity in the flow domain.

3 Test-case description

In cases 17.a and 17.b, the fluid characteristics (water and air, referred by the subscripts l and g for liquid and gas) are the following.

- density: $\rho_l = 1000$ kg.m^{-3}, $\rho_g = 1.1768$ kg.m^{-3}
- dynamic viscosity: $\mu_l = 10^{-3}$ Pa.s, $\mu_g = 10^{-5}$ Pa.s

Paying attention to the space scale of the problem, the surface tension effects are neglected as the space scale of the problem is very large. The gravity norm is $g = 9.81$ m.s^{-2}.

The calculation domain is described by the length L and the height H. The geometrical parameters reads for case 17.a

- $L/2 = 0.6$ m,
- $H = 0.14$ m,
- $h_g = 0.1$ m,
- $h_r < h_l$,
- 0.0005 m $\leq \Delta x \leq 0.002$ m

whereas for test 17.b, we choose

- $L/2 = 0.6$ m,
- $H = 0.14$ m,
- $h_l = 0.1$ m,
- $h_r = 0$ m,
- 0.0005 m $\leq \Delta x \leq 0.002$ m

The mesh size used for the simulations is referred by Δx. Neumann homogeneous boundary conditions are imposed on the upper, left and right limits whereas no-slip conditions are implemented on the lower boundary of the calculation domain.

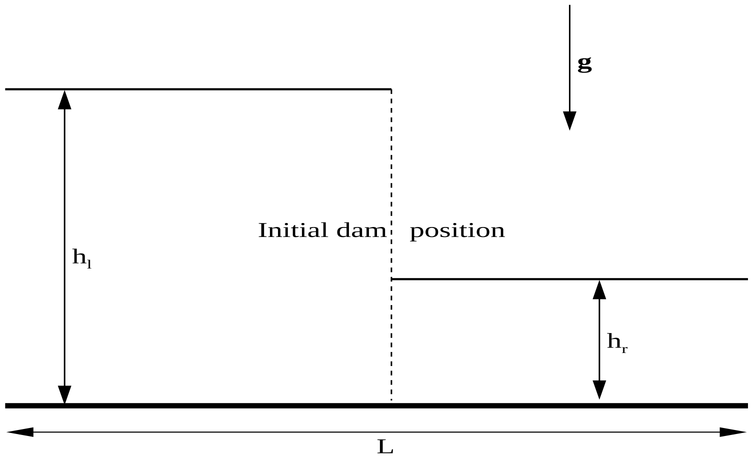

Figure 1: Definition sketch

References

Harlow, F.H., & Welch, J.E. 1965. Numerical calculation of time-dependent viscous incompressible flow of fluid with free surface. *Phys. Fluid*, **8**, 2182–2189.

Martin, J.C., & Moyce, W.J. 1952. An experimental study of the collapse of liquid columns on a rigid horizontal plane. *Phys. Trans. Serie A, Math. Phys. Sci.*, **244**, 312–325.

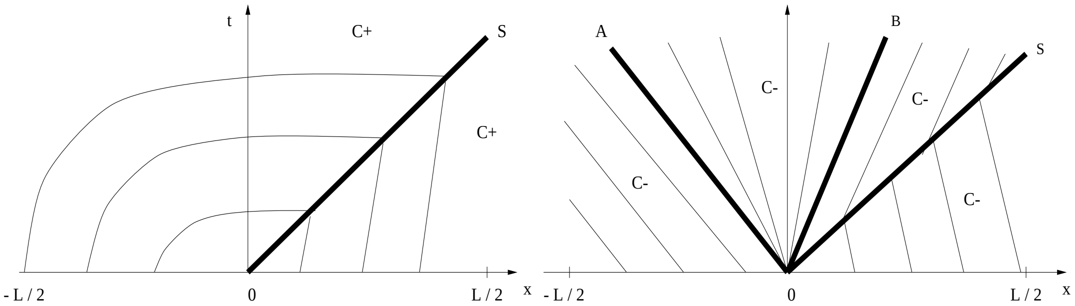

Figure 2: Dam-break flow on wet bottom. Left: description of the characteristic curves $C_+ = u + \sqrt{gh_s}$ in the plane(x,t). Initially, the dam-break occurs at $x = 0$. A shock wave S appears. Right: description of the characteristic curves $C_- = u - \sqrt{gh_s}$ in the plane (x,t). A rarefaction wave is generated between A et B.

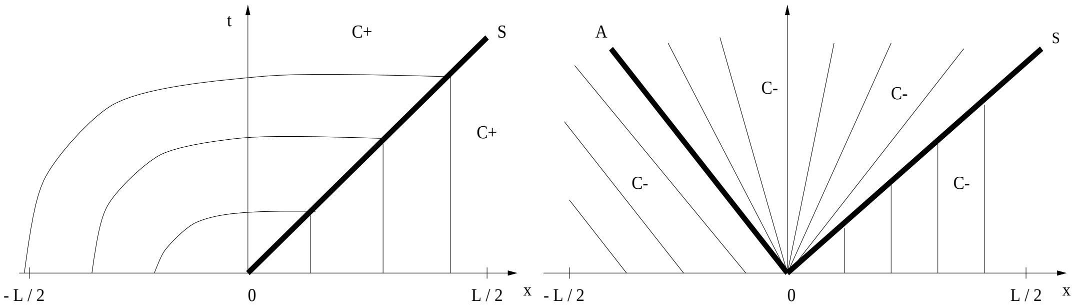

Figure 3: Dam-break flow on dry bottom. Left: description of the characteristic curves $C_- = u - \sqrt{gh_s}$ in the plane (x,t). Initially, the dam-break is situated at $x = 0$. A rarefaction wave appears between A and B. Right: description of the characteristic curves $C_+ = u + \sqrt{gh_s}$ in the plane (x,t). A shock wave is generated in S.

P.K. Stansby, A. Chegini, & Barnes, T.C.D. 1998. The initial stages of dam-break flow. *J. Fluid Mech.*, **374**, 407–424.

S. Vincent, P. Bonneton, & Caltagirone, J.-P. 2001. Numerical modelling of bore propagation and run-up on sloping beaches using a MacCormack TVD scheme. *J. Hydraulic Res.*, **39**, 41–49.

Vincent, S. 1999. *Modeling incompressible flows of non-miscible fluids.* Ph.D. thesis, Speciality: Mechanical Engineering, Bordeaux 1 University, France.

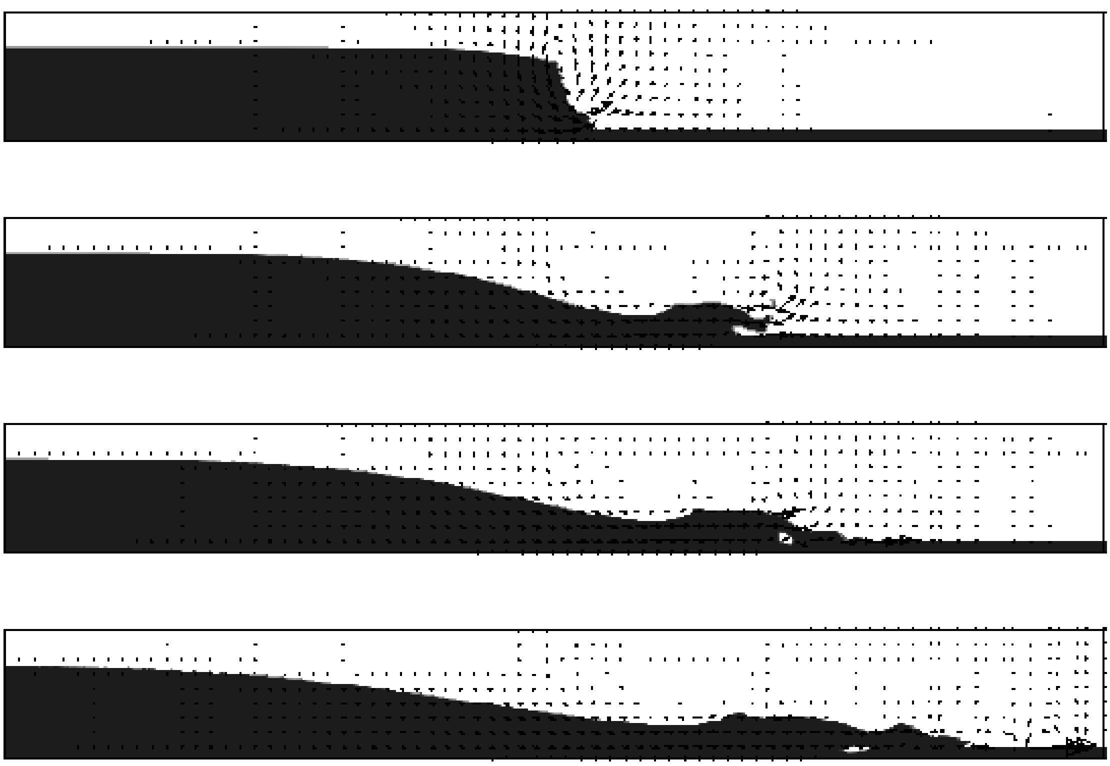

Figure 4: Direct numerical simulation of the dam-break flow on wet bottom with $h_l = 0.1$ m et $h_r = 0.01$ m. The free surface and the velocity field are plotted. The physical parameters are the following : $\Delta x = 0.002$ m, $t = 0.06$, 0.24, 0.3 and 0.42 s (from top to bottom), $Re = 9 \cdot 10^3$ and $0 \leq Fr \leq 3$.