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Simulation of transient flow in channels with Canalflowmodel

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1 CONTENT

2 INTRODUCTION

The aim of this practice is to approach the modelling of free surface flows using simple tools for the mathematical modelling of free surface flows with a mainly one-dimensional character.

There are different tools that provide different useful features for the modelling of this type of flows. One example of a tool is the canalflowmodel (http://canalflowmodel.net). One of the main advantages of this model, from the point of view of its use, is the possibility of saving the information in the cloud by means of a ticketing system. As will be seen throughout the practice, the way to save the information is by modifying the name of the project, which is normally given by the concatenation of a generic identifier and an identifier provided by the user. Another of the advantages of the model is its numerical robustness, since, as we will see, it shows good behaviour in all types of regimes, regime changes and other common phenomena in modelling.

It is proposed to carry out a set of tasks which are summarised in the following points:

- Modelling cases of ideal and rough **dam breaks.**
- Modelling **flood flows** in realistic meanders and performing a sensitivity analysis with respect to Manning's coefficient.

The programme solves the differential equation system of conservation of mass and motion averaged over the wetted section numerically through finite volumes:

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=0 \tag{1}$$

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right)+gA\frac{\partial h}{\partial x}=gA(S_0-S_f) \tag{2}$$

Where (A,Q) are the wetted cross-sectional area and the flow through it respectively, h is the maximum water depth in each section A and g is the gravitational acceleration. The right-hand terms in the motion equation are the bed slope S_0 defined as the derivative (with minus sign) of the bed elevation z_b in the x-direction and the friction loss slope which we will formulate with Manning's law as a function of the roughness coefficient n and the hydraulic radius $R=A/P_m$ where P_m is the wetted perimeter.

$$S_f=\frac{n^2Q\,|\,Q\,|}{A^2R^{\frac{4}{3}}} \tag{3}$$

2.1 DAM BREAK

Using the *dbw2* ticket, we are going to simulate the dam break wave. The ideal dam break is one of the most classical examples of transient problems with exact solution and one of the most used to compare the performance of numerical schemes.

When we have the equation system written per unit width in a plain-bottomed prismatic channel and in the absence of friction:

$$\frac{\partial h}{\partial t} + \frac{\partial hu}{\partial x} = 0 \tag{4}$$

$$\frac{\partial (hu)}{\partial t} + \frac{\partial}{\partial x}\left(hu^2 + g\frac{h^2}{2} \right) = 0 \tag{5}$$

initial conditions with an imaginary discontinuity separating two regions with zero velocity allow us to obtain a solution for the water movement once the imaginary separating wall disappears. The water surface evolution is schematized in Figure 1. The side where the water level was higher is emptied and the side where the water level was lower is filled at the same time. This second side is filled by means of a moving hydraulic jump type wave that advances with constant speed in the absence of obstacles and friction.

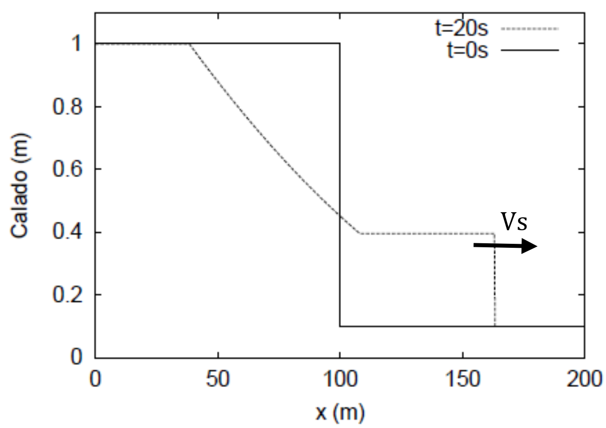

Figure 1 Graphical representation of the setting of an ideal dam break at its initial stage (t=0s) and after 20 sec.

The propagation of a discontinuity in water is physically characterized by the depths and velocities on both sides of the discontinuity and by the propagation velocity of the discontinuity, as shown in Figure 2.

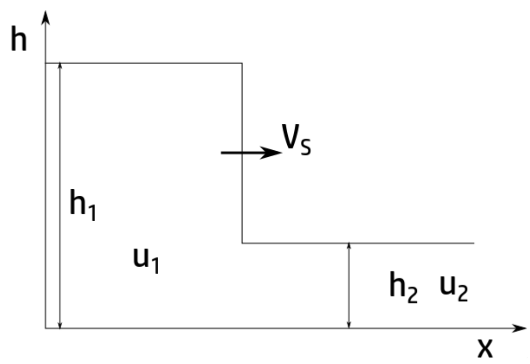

Figure 2 Representation of a discontinuity travelling along the surface

The relationship between these quantities is linked by the Rankine-Hugoniot equations of mass and motion balance. Integral equations of mass and motion in a control volume for a rectangular channel:

$$\delta\left[h(u-V_S)\right]=0$$

$$\delta\left[h(u-V_S)^2+g\frac{h^2}{2}\right]=0$$

are used, where $\delta(x)=x_2-x_1$ applies to a determined variable *x* and the velocity u-U is related to an observer moving with the velocity V_s. Therefore, having 2 binding equations and 5 unknowns (h_1, h_2, u_1, u_2 *and* V_s), the system will have 3 degrees of freedom. Knowing the depths h_1 and h_2, and the downstream velocity u_1, it is possible to obtain the upstream velocity u_2 and the propagation velocity of the discontinuity V_s theoretically from the following equations:

$$V_S=u_2+\sqrt{g\frac{(h_1+h_2)}{2}\frac{h_1}{h_2}}$$

$$u_1=V_S\frac{h_2-h_1}{h_1}+\frac{h_2u_2}{h_1}$$

2.1.1 Exercises

1. **Simulation of the ideal case**. Assume a channel with a rectangular cross-section, horizontal and frictionless. The initial discontinuity of depths is 4m : 3m, this generates a shock wave travelling to the right. Observe the evolution of depths and flow rates.
   Estimate the velocity U of the front by simulation and compare it with the theoretical prediction. Repeat the calculation with a finer mesh.
   Verify by numerical experimentation that in this case a CFL condition less than 1 is numerically stable for this scheme. Evaluate the time step being used at each point in time and who conditions it. To analyze the influence of the initial gradient, repeat for a gradient of 10m: 1m.

2. **Roughness variation**. To analyze the influence of the bed roughness, repeat the cases 4m : 3m and 10m : 1m on the rectangular channel for a non-zero roughness characterized by a Manning coefficient of n = 0.02 (polished concrete). Compare the height of the shock wave

formed and its forward velocity with those of the case without friction. Repeat the same by varying the friction coefficient.

3. **Presence of obstacles**. To observe the modification that waves of this type undergo when they cross a gorge, a widening, or an elevation of the bed, it is necessary to modify the number of cross sections at the start of the simulation. We will solve the problem of dam breaks using the geometrical configuration of channel narrowing on a flat bed saved in practice 1 and a bed obstacle (*obstaclew2*).

2.2 WAVE BEHAVIOUR

In this part of the practice, the behavior of hydrographs as they are transported along channels and rivers will be analyzed. To do this, a transient flow wave, a hydrograph, will be distributed along two different channels: one horizontal and frictionless, and the other with a slope and friction.

2.2.1 Propagation in horizontal channel

We will transport a triangular synthetic hydrograph in a horizontal channel to analyze its deformation along the channel.

A new project will be generated, consisting of a channel of rectangular section ($A=bh$, $P_m=b+2h$) and zero slope as shown in figure 1

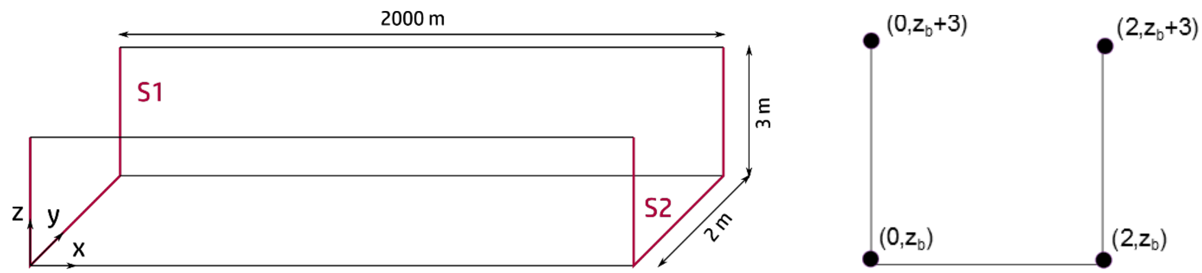

Figure 1 Channel scheme (left) and section scheme

The geometry of section S1 and S2 is the same. The simulation conditions are:

- Initial condition h+z constant: 0.3 m
- Input boundary condition: hydrograph table 1
- Output boundary condition: free flow
- Manning's n: 0
- Simulation time: 3600 s
- Iter data: 10 s

If necessary, you can load the ticket: *wavew2*.

Time [s]	Flow rate [m^3/s]
0	0
200	0.3
400	0
7200	0

Table 1 Channel inlet hydrogram

2.2.2 Exercise

Simulate the case. Observe the peak produced by the waves and analyze it.

2.2.3 Sloping channel transport

A new project will be generated, consisting of a channel with a rectangular section ($A=bh$, $P_m=b+2h$) and a constant slope as shown in figure 2. This can be done by loading the ticket: *propagationw2*

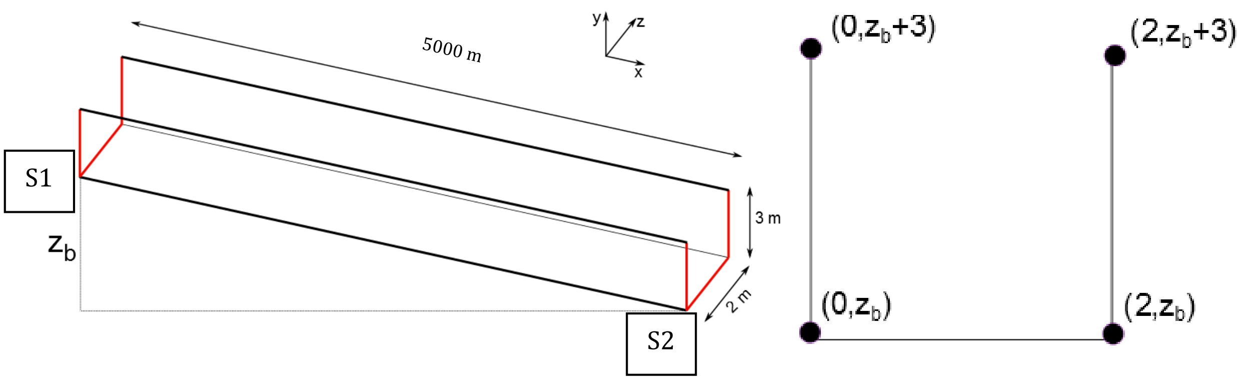

Figure 2 Channel scheme (left) and section scheme

The geometry of the section S1 and S2 is the same except for the origin associated with the height of the section itself, which is defined by the height z_b, which in this case is 0.3m.

2.2.4 Exercise

Simulate the case for two different Manning coefficients:

- n=0
- n=0.011

Observe and analyze the difference between the propagation of the two cases.

2.3 TRANSPORT OF HYDROGRAMS

A new project will be generated, consisting of a channel with a rectangular section ($A=bh$, $P_m=b+2h$) and a constant slope as shown in figure 3. This can be done by loading the ticket: *hidrow2low*

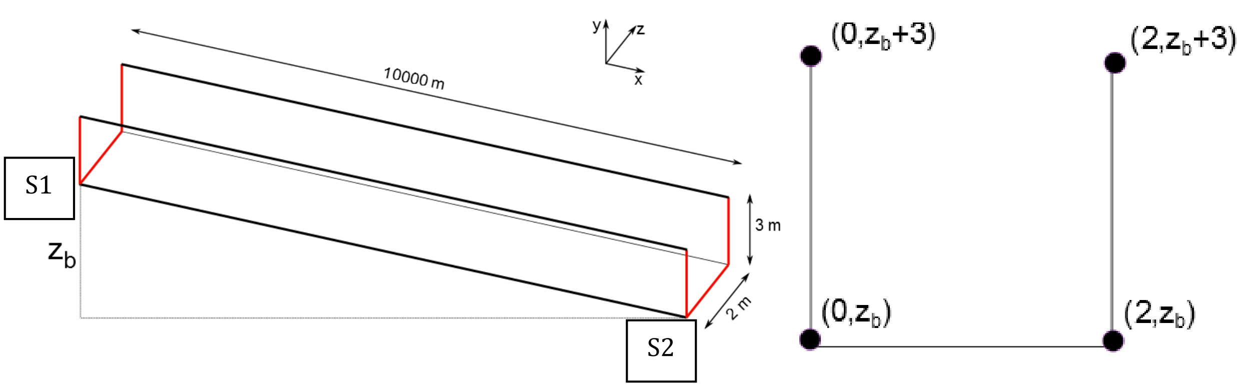

Figure 3 Channel scheme (left) and section scheme

The geometry of the section S1 and S2 is the same except for the origin associated with the height of the section itself, which is defined by the height z_b, which in this case is 2m.

The flow conditions are:

- Inlet: hydrogram from table 2
- Outlet: uniform flow
- Manning: 0.011

Initial condition: constant flow rate Q=0.5 m^3/s

Time [s]	Flow rate [m^3/s]
0	0.5
3600	4
7200	0.5
36000	0.5

Table 2 Channel inlet hydrogram

2.3.1 Exercise

Carry out two simulations with two different frictions:

- n=0.005
- n=0.011
- n=0.03

Analyze and record, for each of the friction coefficients, the arrival time of the wave and the peak it reaches at the output.

Case	Arrival time [s]	Peak Q at outlet [m^3/s]
n=0.011		
n=0.005		
n=0.03		

Table 3 Hydrogram lamination results

For the intermediate Manning case apply two different boundary conditions:

- Uniform flow
- Weir (h_{Crest}= 1 m, b=1.8 m, α=45º)

And analyze changes in arrival time and peak captured at the outlet.