CFD modelling approach for Dam break flow studies

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Rebuttal to Reviewer Ezio Todini

We are extremely grateful to the reviewer for the thorough and detailed review, for the useful suggestions and for pointing out the gaps in text and figures, thus certainly allowing to improve the quality of our paper.

The answers to editor's comments are reported below.

***E:** 3-D model in my view can be proficiently used for scouring analysis around piers and in many other interesting cases.*

A: The simulation of a dam-break problem, as a fluid problem, may be approached in different ways. Different levels of approximations may be used and in this paper we compare the shallow water approach (basically a two-dimensional approach with a simplified consideration of the altitude dimension) and the fully NS tridimensional approach coupled to the VOF model for tracking the air-water interface. We still think that a fair and critical comparison of these approaches could be useful for the scientific community, in order to highlight advantages and disadvantages of both models on dam break problems.

The use of three-dimensional models in such problems is worth being investigated, as better explained in the following discussion, and assessed by several examples that could be found in the recent literature:

- Crespo, A.J.C., Gomez-Gesteira, M., Dalrymple, R.A. Modeling dam break behavior over a wet bed by a SPH technique 2008 Journal of Waterway, Port, Coastal and Ocean Engineering 134 (6), pp. 313-320

- Quecedo M., Pastor M., Herreros M.I., Fernandez Merodo J.A., Zhang Q. Comparison of two mathematical models for solving the dam break problem using the FEM method (2005) Computer Methods in Applied Mechanics and Engineering, 194 (36-38), pp. 3984-4005.

- Gómez-Gesteira, M. and Dalrymple, R.A. (2004), Using a three-dimensional smoothed particle hydrodynamics method for wave impact on a tall structure, J. Waterway, Port, Coastal and Ocean Eng., 130(2): 63–69.

- D. Dutykh, D. Mitsotakis. On the relevance of the dam break problem in the context of nonlinear shallow water equations. Accepted to Discrete and Continuous Dynamical Systems, 2009

- D. Liang, B. Lin and R.A. Falconer, Simulation of rapidly varying flow using an efficient TVD-MacCormack scheme, International journal for numerical methods in fluids 53 (2007), pp. 811–826

As already pointed out in some of the previous papers, the main assumptions adopted in the derivation of the Shallow Water Equations are invalid close to steep variations (or discontinuities), even if they, in principle, admit discontinuities in the solution. This inconsistency may also affect the results of dam-break modelling in some cases. Obviously, these effects are more evident in the region close to the dam

In addition, we are already investigating the feasibility of the three-dimensional model for those applications suggested by the reviewer. In particular, we are investigating pseudo-natural meandering Flows, (Stoesser, 2009, Advances in Water Resources, doi:10.1016/j.advwatres.2009.11.001), interaction of a flood wave and a structure in a closed tank (Gómez-Gesteira, M. and Dalrymple, R.A. (2004), J. Waterway, Port, Coastal and Ocean Eng., 130(2): 63–69), and landlside generated impulse waves (Watts, 2003, Nat. Hazards Earth Syst. Sci., 3, 391-402, Biscarini, C., Computational Fluid Dynamics Modeling of Landslide Generated Water Waves, Landslides, in press). Future works will be focused on these test cases.

***E:** Although called dam-break, from its originator Danny L. Fread of the US-NWS (unfortunately not quoted by the authors), who developed a 1-D full Saint Venant model…*

A: This reference has been added in the revised version of the paper

***E:** …. From the original studies in 1-D it already emerged that the dynamical and inertial terms, which are essential to correctly represent the near field (close to the breach or the dam failure), have scant effect in the far field (in reality not that far from the dam, most of the time less than 1 km). Taking into account the extremely large computational effort already required to represent the flooding in 2-D, in a real dam failure case the basic question to be answered must be: what is the benefit of a using a 3-D representation of the routing phenomenon, as opposed to a 2-D, if the interest lays not in the proximity of the dam where it is hard to believe that there will be inhabitants and properties at stake, but downstream, where the flooding risk can be extremely large?*

A: The analysis made by the editor is absolutely shareable, and we think that it is worth to be included in our discussion. We absolutely agree with him on the larger effect on the near-field and this point has been deepened and highlighted in the revised version of the paper. However, a discussion on this point was already present, as, in order to perform a fair comparison, we showed the numerical results at different distances from the gate (400 m, 500 m, 600m and 700 m), concluding that the 3d, the 2d and the 1d approaches could be even coupled in cascade to obtain extremely accurate results with a limited computational approach. The coupling could be done on the basis of the water surface variation along cross section, as suggested in the paper.

It is however important to point out that the computational effort is absolutely acceptable, as the present 3D simulations have been carried out in a PC with processor AMD phenom Quadcore 2.33 GHertz and 3.2 Gigabyte of RAM memory. The SW model runs on Windows XP operative system, while the NS-VOF on Lynux Ubuntu 9.10 operative system. The simulation of the first test case, using a dimension of mesh-side of 1m, took 0.25 h and 2 h, for the 2D model and the 3D model, respectively. These data have been reported in the revised version of the paper.

The advent of extremely more powerful resources is paving the way to the use of Computational Fluid Dynamics (CFD) in an increasing number of scientific and engineering disciplines, including hydraulics and specifically flooding. Three-dimensional simulations, much more detailed than the present, could be performed today with acceptable computational effort. Nowadays, in fact, a multiprocessor linux clusters or a workstation cost few thousand dollars and allow simulations with a high level of detail also on the geomorphologic characteristics of the studied site.

Just to make a fair comparison, a notebook today is much faster (processor) and greater in memory than a supercomputer of 15-20 years ago, when the shallow water simulations were already applied to dam break problems (i.e. Elvius, T. & Sundstrom, A. (1973) "Computationally efficient schemes and boundary conditions for a fine mesh barotropic model based on the shallow water equations," Tellus 25, 132-156). Therefore, we can easily state that the NS-VOF model today is even less computationally expensive than the shallow water model 15 years ago.

On the other hand, it is important to note that, even if the overall computational effort is absolutely affordable, the number above also highlight that the SW model may be one order of magnitude faster than the NS. This means that it could be the ideal candidate for large computational domains, once the assumptions are verified. The Navier–Stokes approach is more suitable for modeling smaller domains where the knowledge of the three-dimensional structure of the flow is needed.

The above discussion has been introduced in the revised version of the paper.

E: *if the interest lays not in the proximity of the dam where it is hard to believe that there will be inhabitants and properties at stake….*

A: We partially agree with the reviewer on the fact that most times (but not always, as explained below!) properties and inhabitants stay far from the dam. However, this kind of analyses is not necessarily related to risk analyses, as the comprehension of fluid dynamic phenomana and related effects in the near-field may be useful for several technical and/or scientific reasons (i.e. water-structure interaction, dam fracture dynamics, erosion, effects on flora, fauna and close constructions, material transport etc.). The three-dimensional model may provide a complete and detailed information on the physical quantities in space and time, that in turn give information on the potential flood evolution especially in terms of water depth, free surface profile, flow velocity, wave front dynamics etc. also over complicated terrain profiles and frequent discontinuities.

It is also worth to say that there are cases of inhabitants and properties close to the dam (Vajont (Italy), Valfabbrica (Chiascio river, Italy), Hosler Dam (city of Ashland Oregon USA), Dams of Lake Pontchartrain (New Orleans USA), etc.).

E: *While in the case of the dyke failure, the question is what is the improvement that a 3-D model can provide when the phenomenon is fundamentally ruled by a 180° expansion? I must admit that I could not find this discussion in the paper, and, moreover, I am strongly convinced that the interpretation given by the authors is not supported by the displayed results.*

A: This discussion has been introduced in the revised version of the paper. The derivation of the Shallow Water equations is based on the assumptions that vertical velocities and accelerations are negligible. This assumption results into a hydrostatic pressure distribution. However, when high free surface gradients exist, such as those at the failure site during the first instants, or when physical obstacles or steep changes on the bed slope are encountered by the flood wave, this assumption is no longer valid. Therefore, non-simplified models are needed to accurately solve the three-dimensional structure of the flow in these areas (see for example: L. Fraccarollo, E.F. Toro, Experimental and numerical assessment of the shallow water model for two-dimensional dam-break problems, J. Hydr. Res. 33 (1995) 843–864; P.K. Mohapatra, V. Eswaran, S.M. Bhallamudi, Two-dimensional analysis of dam-break flow in vertical plane, J. Hydr. Engng. ASCE 125 (2) (1999) 183–192).

E: *1) In both test cases the integration domain is practically one dimensional. In particular in the first example, a real 2-D problem must be solved by allowing the water also to expand in the direction of the arrows. Therefore the effect of the inertial terms is amplified and even if the interpretation of results was correct (which is not in my opinion) one could not really assess if a 3-D model may produce improved results.*

A: The question is not completely clear to us. Both physical domains are three-dimensional in the simulations. With the shallow water approach (that practically does not solve the equations along the z-axis) the first domain is practically bidimensional and the second one may appear one-dimensional. However, in the latter one should consider that the wall boundary conditions at both sides have an effect on the flow field development.

The editor is right in stating that, with the 1st test case, one could not really assess if the 3D model is better, as no analytic or experimental results are available. However, it is a widely used test case and it is important, in our opinion, to highlight the differences between the 3d and the SW approaches. The second test case may indeed give indications on possible better predictions of the 3d model. A third test case has been added.

E: *2) Moreover, in the first test case there is no comparison of the results with actual observations or with a theoretical solution. How do the differences between the two approaches compare with the inevitable errors induced by the geomorphologic representation of the ground and its discretisation combined to the effects of the assumed friction factors and the hypothesis on the dam or dyke collapse?*

A: The first test case has been chosen as widely simulated in literature with the SW approach with the aim of testing the model to simulate the front wave propagation over a dry bed, with particular attention to the 2D aspect of the flow motion. Analytical and experimental reference solutions for this test case are not available.

Concerning the geomorphologic representation of the ground, its discretisation and the related friction effects, we totally agree that they may induce (even large) errors. However, we can't say "a priori" how these errors would compare with the differences between the two approaches". The aim of the present paper is to highlight the differences between the two approaches and reference test cases have been used to this aim.

E: *3) There is no mention of the computational requirements of a 3-D model (or a discussion) when the simulation inevitably must extend for many kilometres (probably tenths of kilometres) downstream the breach or the dam failure point.*

A: As already stated above, the computational effort required by three-dimensional simulations is absolutely acceptable with nowadays available computational resources. Again it must be stressed (and it is done in the revised version of the paper) that the Shallow Water approach should be considered as a major candidate for computations involving large domains, leaving the Navier–Stokes approach for fine calculations where the knowledge of the three-dimensional structure of the flow is required. The idea of using in cascade 3d and 1d models (already reported in the paper) may help to make accurate simulations extended for many kilometers and this should be the next step in our research.

E: *Going more in detail. With reference to the first example, the comparison produced in Figure 4, 5, 8 and 9 relates to the near field which implies the representation of a real 3-D field. It is obvious* *that the 2-D solution will differ from the 3-D's. I must admit that from what I see in Figs. 4 and 5 the 2-D shows astonishing good performances, since the differences are quite small.*

A: The shallow water model is capable of reproducing the literature solution, as the latter has been also performed with a shallow water model. However, the differences between the two models are highlighted in the figures, thus giving the reader the possibility of making his own opinion as the editor did.

E: *Then the authors point out that the 2-D model at a distance of 600 m has a delay in the front transfer time of about 4 seconds and a peak attenuation of 20% with respect to the 3-D model, and they state "It is important to note that this shift time assumes a very important role in a real basin scale, as an incorrect prediction of the lead time may yield relevant errors in the emergency planning and risk mitigation activity". I believe this statement to be meaningless due to the fact that 4 s at 600 m will be only a few minutes several tenths of kilometers downstream, and that emergency plans are based on hours not on minutes.*

A: We agree with the reviewer that some adjectives on the statement may be excessive. This has been modified in the revised version of the paper. However, stating that the obtained results are "meaningless" is excessive too. The authors, still to make the comparison in a fair way, gave the numerical results, 4s of delay at 600 m (now 6 s). Therefore, it may be correct to make a more prudent statement, but we should leave the reader making his own opinion. The fact that the differences are irrelevant may be itself a result that is worth to be published.

Moreover, we may state that often "emergency plans are based on hours not on minutes", but this statement cannot be considered universal, especially for the people and the buildings close to the dam.

E: *Another intriguing question is the second peak in Fig. 9 relevant to the 2-D solution in terms of discharge, which does not appear in Fig. 8 in terms of water depth. Do the authors have an explanation for it? It is very strange and may induce to think to an effect of the downstream boundary conditions. And why it does not appear in the 3-D results?*

A: On this point the reviewer is absolutely right. The second peak effect was induced by the boundary conditions (too close outlet section). The simulation has been repeated with a larger domain and the paper has been updated. The new figures are reported below.

It must be highlighted that the observed differences between the NS and the SW model are even larger than before. The SW model at a distance of 600 m has a delay in the front transfer time of about 6 seconds and a peak attenuation of 30% with respect to the 3-D model

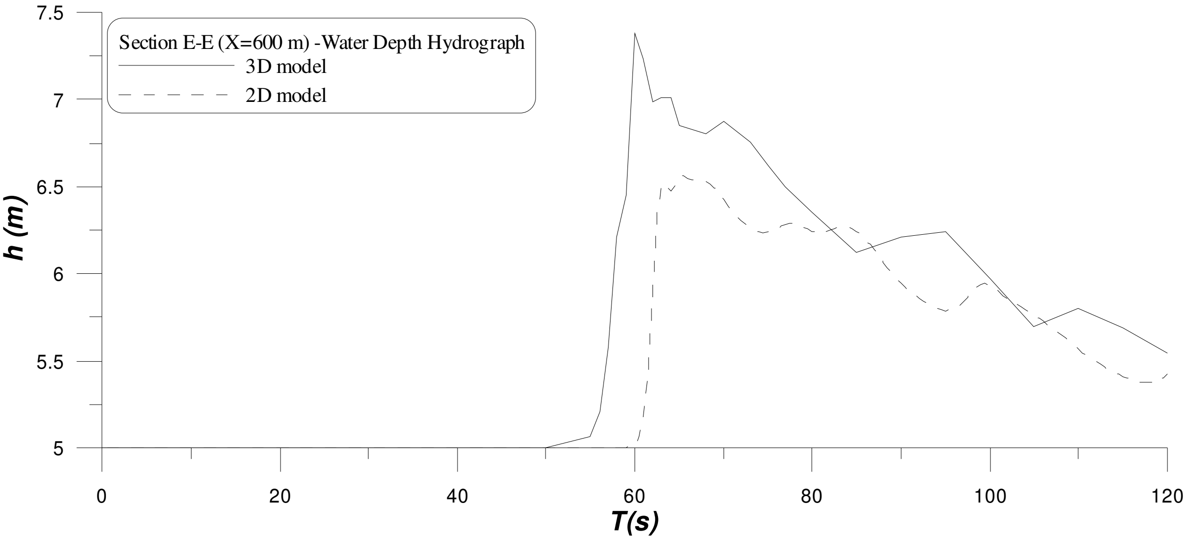


Figure 8

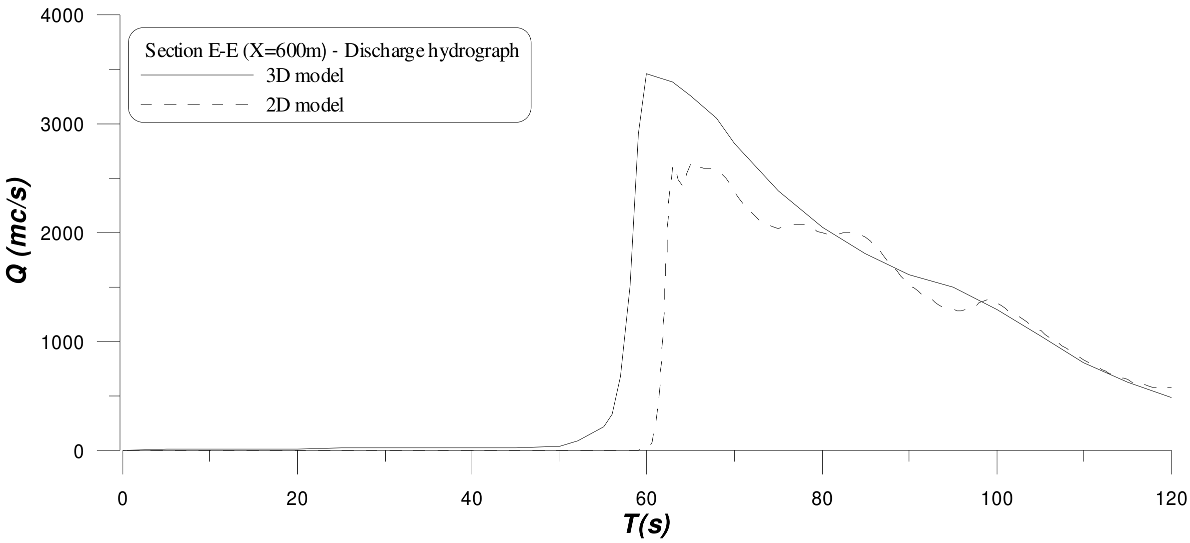
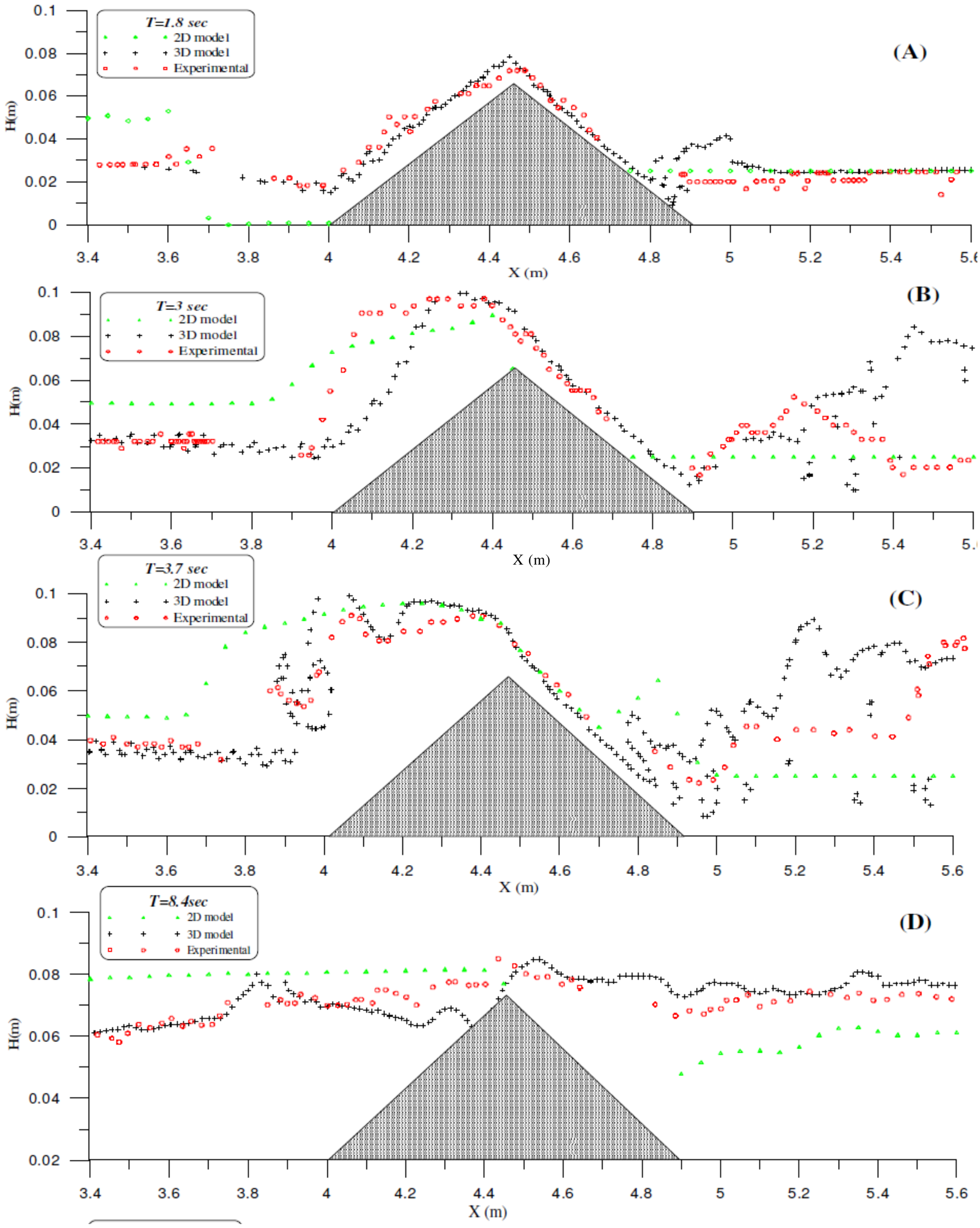


Figure 9

E: *Finally in the description of the second test case results, the authors say that the 3-D model has a globally better behavior. But this is not fully substantiated by the displayed results. For instance at t = 8.4 s the free surface profile is better reproduced by the 3-D model upstream the obstacle, but is better reproduced by the 2-D mode downstream. Additionally Fig. 13 is almost unreadable due to the scale.*

A: The free surface profile was obtained by some discrete points of the esperimental observation and successive interpolation. The number of points to reconstruct the experimental profile have been drastically increased and the new figures, reported below, highlight that the 3D model produce better results, especially upstream, but also downstream (except for the 3 s frame).



E: *Therefore my conclusions are:*

1) the 3-D model developed by the authors may be an extremely valuable piece of work.

2) the authors, for all the above discussed reasons, in my view failed at demonstrating the superiority of the 3-D approach for the solution of the dam break or dam breach problems.

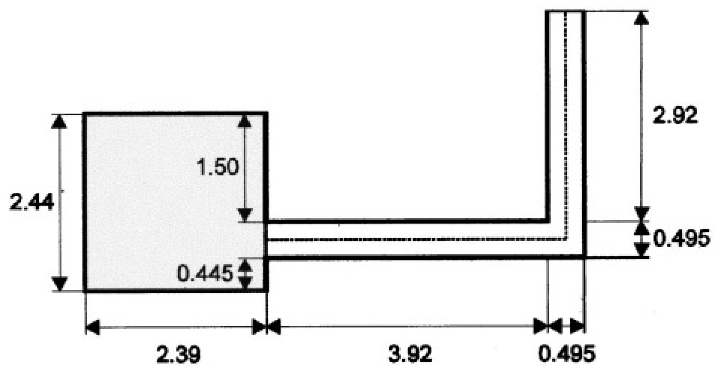
3) the authors must:

3.1) either, following the above provided comments, prove the improvements obtainable on a real case for which actual observations are available but also considering the relevant costs to pay in terms of computational efforts and time consumption; or

3.2) prove the validity of the approach for the solution of other problems more relevant to the near field.

A: Regarding the conclusive statements of the reviewer, we would like to highlight the following:

- The aim of the paper is not to demonstrate the superiority of the 3-D approach for the solution of the dam break or dam breach problems, but to highlight the differences between the SW approach and the fully 3D approach (with VOF). The 3d approach should not substitute the SW, but it could be effectively applied when the hypotheses behind the SW approach may lead to high errors and in the near-field region. Regarding the latter point, in fact, the two methods could be even combined (also with the 1D approach). The reader should be free also to make his own opinion on the showed results. We modified the text in order to highlight the main message of the paper.
- In order to improve the discussion and the comparison, if necessary, another test case has be added. Weber et al. (2001 J. Hydraul. Eng.) performed detailed measurements of steady flow at a 90° open-channel junction, showing the complex three-dimensional velocity distribution in the sharp bend. The test intend to document the description of the dam-break phenomenon in the case of a 90° bend. It is well known that rivers have a natural trend to meander. Depending on their formation process and on the local geology, the meanders can be large, smooth curves, or on the opposite, very narrow with sharp bends. For example Robertville dam in the Warche valley (Belgium), corresponds to this latter case. The purpose of the test is to investigate more deeply the problem posed by sharp bends, by means of a simplified case: a dam-break flow in a channel with a 90° bend . Simulations are compared with the measurements in an laboratory-channel with a 90° (S. Soares Fraza and Y. Zech, 2002 Journal of Hydraulic Engineering)



Channel with 90° bend. Plane view (dimension in m)

Several conclusions drawn out are a good perspectives for future research.