SIMULATION OF SUPERCRITICAL FLOW IN CROSSROADS: CONFRONTATION OF A 2D AND 3D NUMERICAL APPROACHES TO EXPERIMENTAL RESULTS

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Abstract
During severe flooding of urban areas, the water in the streets can reach a depth of a meter or more, causing huge economic losses, and possible loss of life. We therefore need to be able to predict flood propagation in urban areas, in order to design suitable protection (possibly by directing the flood waters to previously identified sacrificial zones) and to develop realistic emergency planning. Because of the complexity of the problem, and the number of different situations that have to be considered, the most suitable approach is by numerical simulation, usually by solution of the Saint Venant equations. In general, the 1D Saint Venant equations provide a reasonable model for the flow in individual streets, but they do not really apply to the flow in street intersections where the flow is strongly two or three-dimensional.
It is very important to know the inundated water depths and velocities for flood control and damage mitigation. Through an analysis of the characteristics of flooding waves, we can find out that area of flooding is generally much larger than the inundated water depth, that the variations of flooding waves in the vertical direction can be ignored, and that the water pressure is hydrostatic, i.e., the flooding wave has the characteristics of shallow water waves (Weiyan, 1998). Therefore, 2D shallow water equations were used to describe the transportation of flooding waves in the temporal and in the spatial domains.
In general, numerical simulations of 2D shallow water equations can be carried out by the following four methods: (1) finite element method (Akanbi and Katopodes [1]); (2) finite difference method (Fennema and Chaudhry [2]) and (Garcia and Kahawita [4]); (3) characteristic method (Katopodes and Strelkoff [5]); and (4) finite volume method (Zhao et al. [12, 13]), (Yoon and Kang [11]) and (Zhou et al. [14]). The finite volume method is widely used to solve the 2D shallow water equations and to simulate the flood in an urban environment. Recently, Mignot [7] used the code Rubar20 (2D) developed by Paquier [8] for modeling the flood in urban area. The code is based on a finite volume method on unstructured grid and uses an explicit scheme of Van Leer with second order accuracy in time and space.
Concerning the 3D simulation, many codes exist, which solve the Reynolds-averaged Navier-Stokes (RANS) equations. The most classical approach for this kinds of codes is a 3D finite volume method associated with a k-ε turbulence model (Kouyi et al. [6]) and (Vazquez et al. [9]). In our work, the code FLUENT [3] is used with a calculation of the free surface by the volume of fluid (VOF) model (Versteeg et al. [10]).
In this paper, we present the Runge-Kutta Discontinuous Galerkin (RKDG) method in order to study the propagation of flood through the crossroads in the city. A discontinuous finite-element space discretization with a second order Runge-Kutta time discretization is used to solve the two-dimensional Saint Venant equations. The scheme is well suited to handle complicated geometries and requires a simple treatment of boundary conditions and source terms to obtain high-order accuracy. The explicit time integration, together with the use of orthogonal shape functions, makes the method for the investigated flows computationally more efficient than comparable second order finite-volume methods. The study is organized around three aspects: the prediction of the water depths, the location of the right and oblique hydraulic jumps in the crossing and especially the distribution of the flow discharges in the downstream branches.
The idea is to compare a very complicated 3D model, which takes into account more variables (pressure and turbulence model for examples) with a 2D approach and to show the we can obtain very good results with a 2D approach based on the RKDG method. Therefore, a comparison between the results obtained by this RKDG model and those obtained by a comparable second order finite volume method Rubar20 (2D model) and by FLUENT (3D model) is also done. The experimental results obtained by Mignot (2005) are used to compare and validate the different calculations. A very good agreement between the numerical solution obtained by the

Runge-Kutta discontinuous Galerkin (RKDG) method and the experimental measured data was found. The method is then able to simulate the flow patterns observed experimentally and able to predict well the water depths, the discharge distribution in the downstream branches of the crossroad and the location of the hydraulic jumps and other flow characteristics more than the other methods.
In future work, the numerical code will be applied to simulate real severe flooding event: the octobre 3rd, 1988 flood in Nimes (France), the octobre 20th, 1982 flood in Sumacarcel (Spain), the may 31st, 1982 flood in Bordeaux (France) and the december 3rd, 2003 flood in Oullins (France).

Keywords: Urban flooding; Saint Venant equations; Discontinuous Galerkin method; FLUENT; Crossroad; Supercritical flow

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