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Shallow Water Equations as a Mathematical Model of Whitewater Course Hydrodynamics

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ABSTRACT

The growing popularity of whitewater sports requires that designers plan appropriately attractive canoe slalom courses, simultaneously ensuring the safety of their use. These features strongly depend on flow hydrodynamics, resulting largely from the geometry of the chosen venues and the method of their water supply. Since canoe courses are open channels, the flow is governed mainly by fluid weight and forces of gravity. The selection of the geometric and hydraulic parameters of the venue should be preceded by a detailed analysis of the stream moving down the channel. Predicted supercritical and subcritical flow conditions, as well as the position of some typical whitewater structures can be recognized using scale models. The geometric scale ratio should be chosen so as to ensure small dimensions of the model. Additionally, the Reynolds number should be high enough to satisfy the turbulent flow criteria even at small discharges. Similarity between the prototype and the model is usually determined by the Froude number. The Froude number has been found to be the best to characterize slalom course type and difficulty as it represents streaming in the channel as a whole.

Designing courses for mountain canoeing should be the result of cooperation between hydraulic engineers, the water management sector and experienced canoeists. The parameters of whitewater courses depend on their purpose, as to whether they can be used by professionals or canoeing enthusiasts. What is also important is what kind of sport is to be performed - rafting, slalom, freestyle, and whether it is for competitive or training activities. Regardless of the purpose of the canoe course, its technical aspects should meet several criteria, such as high velocity, safety and an unchanging shape with time, and they should imitate natural mountain rivers.

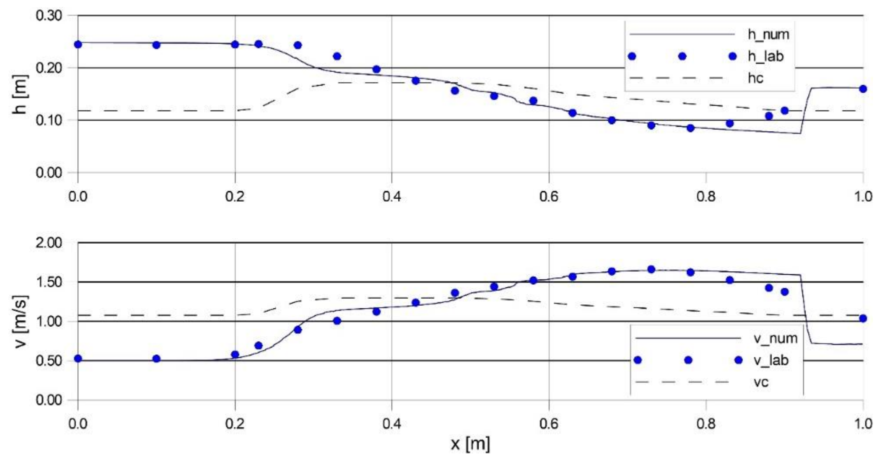

Fig. 1. Measured (lab) and calculated (num) profiles of water depth (h) with the critical depth line (hc) and velocity (v) with the critical velocity line (vc) along the channel constriction longitudinal axis.

Predicting the positions of local hydraulic phenomena, as well as accurately estimating the depth and velocity of the water flow are necessary to correctly configure a whitewater canoeing course. Currently, a laboratory and full 3D CFD modeling are typically used in the design process to meet these needs. The article points to another possibility which can be useful at the preliminary stage of the design. The authors show that a mathematical model of depth-averaged free-surface flow can reliably predict the basic flow dynamics and location of some hydraulic local effects within a whitewater open channel. The results of a numerical simulation of the transcritical flow (Fig. 1) were compared to the flow parameters measured in a laboratory model of a constriction in an open-channel flow (Fig. 2). A satisfactory agreement between the measurements and calculated flow parameters was observed along with the proper reconstruction of hydraulic local effects.

(**a**) (**b**)

Fig. 2. Laboratory experiment in the channel constriction – downstream (a) and upstream (b) view of the transcritical flow.

The relationship between the flow velocity and water depth can be presented as a Froude number (Fig. 3). The map of this criteria number Fr defines quite precisely the spatial structure of the transcritical flow, giving information about the locations of subcritical and supercritical flow zones and about the positions of hydraulic local effects accompanying the flow transitions.

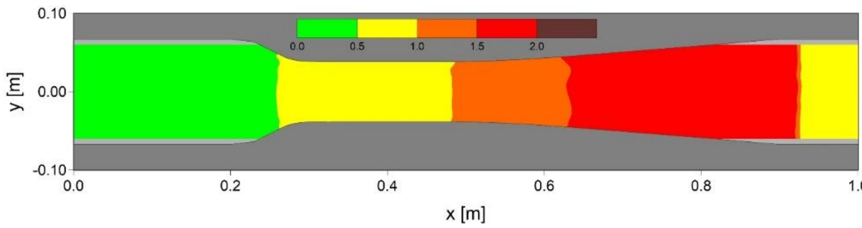

Fig. 3. Froude number [-] horizontal distribution (dimensions in meters).

It can be concluded that the proposed simplified approach to modeling is an efficient method to investigate the main hydraulic features of whitewater flow needed at the concept stage of the design process. This means that cost and time-consuming laboratory and CFD modeling is necessary only at a later stage of the design, after the initial concept of the canoe course has been completed.

It must be underlined that the inner structure of the local whitewater flow phenomena is lost in such numerical simulations due to the vertical averaging of flow parameters in the SWE model. However, the general features of the transcritical flow are properly and sufficiently reproduced to recognize the basic characteristics and mean hydraulic parameters of the flow. This type of whitewater numerical simulation can be useful for the conceptual stage of the design process, when only rough characteristics of whitewater hydraulics are needed.