APPLICATION OF SWASH ON MODELING DAM-BREAK FLOW OVER A TRIANGULAR BOTTOM SILL

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Abstract: *This research presents the application of an open source non-hydrostatic wave-flow model on simulating the dam-break flows over a triangular bottom sill, namely SWASH. The numerical results are compared with measured data obtained from the laboratory experiment which was conducted by S.Soares-Frazão (2007). On overall, the model reproduces the measured flow in the experiment very well. The propagated time and the water levels agree well with the results indicated in the experiment. The accurate simulation of the propagation process provides a good estimation of measured flow on the real experiment. The creaated reflex waves in the propagating procedure are also significantly captured.*

Keywords: SWASH, model, dam-break flows, laboratory experiment.

1. INTRODUCTION

Recently, controlling of flood propagation flows which are normally caused by dam-breaking has attracted the attention of many scientists for the river training and exploitation solutions. In real life, the occurrences of dam-breaking are not expected. However, in order to enhance abilities to respond to such disasters, the laboratory experiments about this phenomena are critical important for further information. Previously, there were several efficient experiments on this type of water propagation flows such as Lauber and Hager reported their experiments on dam-break flows in a horizontal and sloping channel (Lauber and Hager, 1998a, b). Other authors conducted an experiment in sloping channels, with slopes up to 12^0 (Nsom *et al*, 2000). One of the most typical experiments on this was proposed by S.Soares-Frazão which described the transformation of breaking waves over a triangular bottom sill (S.Soares-Frazão, 2007).

On the overall, a dam-break type flow occurs, generating waves passing over the downstream sills. These downstream sills are, at least partially, in an initially dry state, or with very low water level. From a numerical model point of view, the initial dry state might cause difficulties to simulate such events. This type of flow is usually described by the shallow water equations, while wave propagation on a dry bed might cause instabilities as the water depth is approximate zero and the computed velocity might become excessively large. In addition, the presence of bed slope, either upwards or downwards makes the problem more difficult to resolve. In 1994 a special conference namely Modeling of Flood Propagation over initially dry areas had been held to establish the state of the art in mathematical modeling of flood propagation over initially dry areas, in which solutions for the above problem were proposed. However, these models are not as robust as expectation.

In addition, thanks to the development of computation and numerical methods in recent years, the Reynolds-averaged Navier–Stokes equations for water waves have been solved perfectly. On the basic of this achievement many extremely robust wave models have been conducted. Among these models, SWASH (Simulating WAves till Shore) code provides

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the most efficient model in which application with a wide range of time and space scales of surface waves and shallow water flows in complex environment are allowed. This model has been demonstrated to be capable to model many type of waves and hydrodynamic processes in different flow environments. It can simulate non-hydrostatic, free-surface, rotational flows in one or two horizontal dimensions. Accordingly, this research makes a comparison of the results between SWASH model and laboratory experiment of S.Soares-Frazão on the dam-break flow over a triangular bottom sill, in order to assess the abilities of this numerical non-hydrostatic wave-flow model to handle propagation of flood.

2. SIMULATING WAVES TILL SHORE (SWASH) SOURCE CODE

SWASH source code has been developed by Delft University based on the previous code, namely SWAN. It is a non-hydrostatic wave-flow model in which the non-linear shallow water equations are used to predict wave-flow transformation. In addition, it is not only an extremely convenient and open access source code, but also can simulate a wide range of hydraulic processes. It is highly flexible, easily extendible concerning several functionalities of the model. The operationally utilization of SWASH can be access via the website (http://swash.sourceforge.net). This operational use is evolved on the basic combination of several elements and characteristics. It is based on an explicit, second order finite difference method for staggered grids whereby mass and momentum are strictly conserved at discrete level. The second order leapfrog scheme is adopted with the respect to time integration of the continuity and momentum equations. The compact difference scheme for the approximation of vertical gradient of the non-hydrostatic pressure is applied in conjunction with a vertical terrain-following grid, permitting more resolution near the free surface as well as near the bottom for resolution the frequency dispersion up to an acceptable level of accuracy. The more details of these elements and characteristics, as well as its underlying rationale were published by Zijlema and Stelling (2008).

Moreover, SWASH takes as its starting point the incompressible Navier-Stokes equations for the computation of the surface elevation and currents. The depth-averaged, non-hydrostatic, free-surface flow can be described by nonlinear shallow water equations as following:

$$\frac{\partial \zeta}{\partial t} + \frac{\partial hu}{\partial x} + \frac{\partial hv}{\partial y} = 0 \qquad (1)$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + g\frac{\partial \zeta}{\partial x} + \frac{1}{h}\int_{-d}^{\zeta}\frac{\partial q}{\partial x}dz + c_f\frac{u\sqrt{u^2+v^2}}{h} = \frac{1}{h}\left(\frac{\partial h\tau_{xx}}{\partial x} + \frac{\partial h\tau_{xy}}{\partial y}\right) \qquad (2)$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + g\frac{\partial \zeta}{\partial y} + \frac{1}{h}\int_{-d}^{\zeta}\frac{\partial q}{\partial y}dz + c_f\frac{v\sqrt{u^2+v^2}}{h} = \frac{1}{h}\left(\frac{\partial h\tau_{yx}}{\partial x} + \frac{\partial h\tau_{yy}}{\partial y}\right) \qquad (3)$$

Where t is time, x and y are located at the still water level and the z-axis pointing upwards, $\zeta(x, y, t)$ is the surface elevation measured from the still water level, d is the still water depth, or downward measured bottom level, $h = \zeta + d$ is the water depth (Figure 1), $u(x, y, t)$ and $v(x, y, t)$ are the depth-averaged flow velocities in x- and y-directions, respectively, $q(x, y, z, t)$ is the non-hydrostatic pressure (normalized by the density), g is gravitational acceleration, c_f is the dimensionless bottom friction coefficient, and τ_{xx}, τ_{xy}, τ_{yx} and τ_{yy} are the horizontal turbulent stress terms.

In terms of one-dimension (the test case in this paper), the shallow water equations in non-conservative form is elucidated as following:

$$\frac{\partial \zeta}{\partial t} + \frac{\partial hu}{\partial x} = 0 \qquad (4)$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + g\frac{\partial \zeta}{\partial x} + \frac{1}{2}\frac{\partial q_b}{\partial x} + \frac{1}{2}\frac{q_b}{h}\frac{\partial(\zeta - d)}{\partial x} + c_f\frac{u|u|}{h} = \frac{1}{h}\frac{\partial}{\partial x}\left(h\nu_t\frac{\partial u}{\partial x}\right) \qquad (5)$$

$$\frac{\partial w_s}{\partial t} = \frac{2q_b}{h} - \frac{\partial w_b}{\partial_t} \quad \text{where} \quad w_b = -u\frac{\partial d}{\partial x} \qquad (6)$$

$$\frac{\partial u}{\partial x} + \frac{w_s - w_b}{h} = 0 \qquad (7)$$

In which, q_b is the non-hydrostatic pressure at the bottom, w_s is the velocity in z direction at the free surface, w_b is the velocity in z direction at the bottom. The solutions of these equations are in detailed dissemination of researches conducted by Stelling and Zijlema (2003), Zijlema and Stelling (2005) and Zijlema et al. (2011).

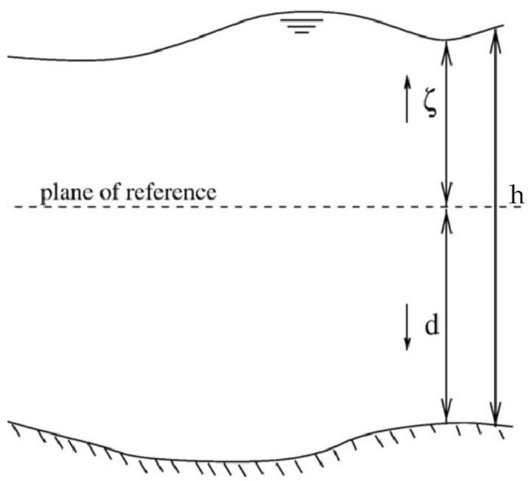


Figure 1. Water area with free surface and bottom (modified from Zijlema and Stelling 2008)

3. EXPERIMENTS TEST CASES

S.Soares-Frazão established a flume experiment results on transformation of breaking waves over a triangular bottom sill. The flume is 5.6 m long, 0.5 m wide, with glass walls. The upstream reservoir extends over 2.39 m and is initially filled with 0.111 m of water at rest. Downstream from the gate, the channel is dry up to the bump with the length of 1.61m. After that a symmetrical bump is set up with 0.065 m high and has bed slopes of ±0.14. Downstream from the end of the bump, a pool contains 0.02 m of water at rest, and a wall closes the downstream end of the channel. The corresponding experimental set-up is shown in Figure 2.

The gate separating the reservoir from the channel can be pulled up rapidly by means of a counterweight and pulley system that allows simulating an instantaneous dam break. At the downstream end of the channel, because of the presence of the wall, the set-up constitutes a closed system where water flows between the two reservoirs and is reflected against the bump and against the upstream and downstream walls. The Manning friction coefficient for the channel was estimated under steady flow conditions, without the bump, and it was found to be 0.011 sm$^{-1/3}$.

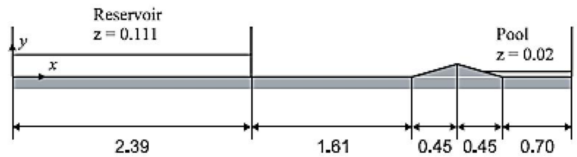


Figure 2. Experimental set-up and initial conditions (modified from S.Soares-Frazão, 2007)

Along the channel, three resistive wave gauges located at x_1 = 5.575m (G1), x_2 = 4.925m (G2) and x_3 = 3.935m (G3) (x_0 = 0 at the upstream end of the reservoir) are used to measure the flow as shown in Figure 3. In addition, High-speed CCD cameras were used to film the flow through the glass walls of the channel at a rate of 25 images per second. As the experiments showed a good repeatability, it was possible to combine the images obtained from different experiments to form a continuous water profile.

Figure 3. The wave gauge positions (modified from S.Soares-Frazão, 2007)

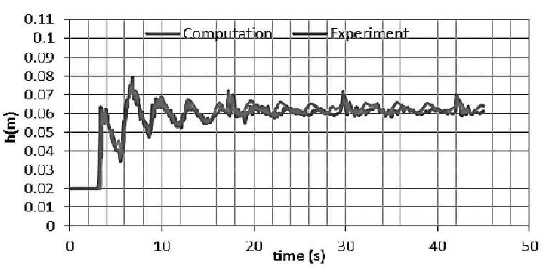
4. MODEL SETUP

The basic of the SWASH code is to provide an efficient and robust model that allows a wide range of time and space scales of surface waves and shallow water flows in complex environments to be applied. In this analysis, numerical simulations are performed with SWASH in a one-dimensional mode with the grid interval of Δx = 0.01 m, initial time step of Δt = 0.01 s, and one layer of water. The turbulent mixing is not taken in account. The discretization is employed for u/v−momentum equation. The standard central difference scheme is used. The time integration is explicit with the Courant-Friedrichs-Levy (CFL) condition in which the value of Courant number is in range of 0.05 to 0.1. The beginning time of the first field of the variable is 0; the simulation period is 125 s, which is long enough to get a steady-state condition. The initial conditions for the model are as follows: the boundary is one full side of the computational grid; the constant discharge to the boundary is imposed by means of time series; the sponge layers are not employed; the Manning formula is activated in which the dimensionless friction coefficient (c_f) in the governing equations is computed through Manning coefficient. In this research, the Manning coefficient is chosen to be the same with that of S.Soares-Frazão (2007) experiment with n=0.011 $sm^{-1/3}$.

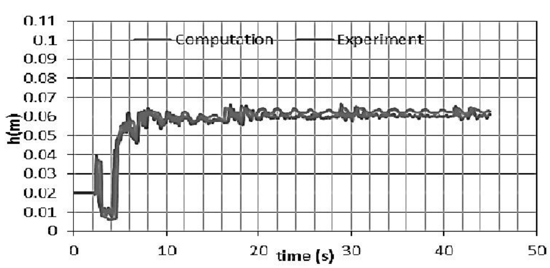
5. RESULTS AND DISCUSSION

5.1. The comparison of water level between computation and the experiments at three wave gauges

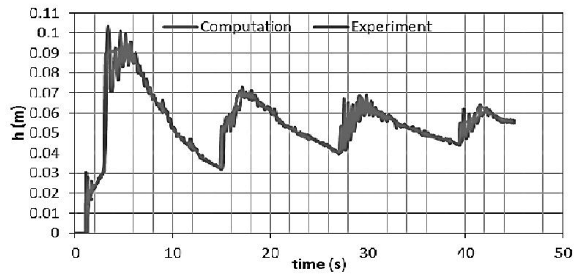
The computed and measured water flows across the flume are compared for the three observed wave gauges. SWASH captures the overall variations of flows very well. The results of computation are highly close to the experiment. The propagation time and the water levels agree well with the results indicated in the experiment. The results of the comparison at the gauges G1, G2 and G3 are respectively shown in Figures 4(a), 4(b) and 4(c).



(a) Gauge G1 (5.575m)



(b) Gauge G2 (4.925m)



(c) Gauge G3 (3.935m)

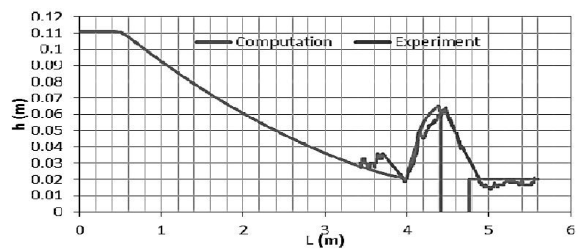
Figure 4. Comparison of water level profile at the wave gauges

However, some small differences can be revealed in duration from t = 3 s to *t* =5 s at the gauge G3 which is located immediately upstream of the obstacle bump. Before the wave comes to this gauge, the initial water depth here is zero. Moreover, when the fast wave arrives, rushing up the slope, it is slight slowed down by the present of the bump. In this case, the experimental flow was recorded the propagation with slightly reflection of several bores, while in the computational simulating these factors may be restricted for no numerical elements against reflected waves are imposed. In addition, the space scale of the experiment may cause some discrepancies in comparison with that of computational space scale. Although SWASH code provides the efficient model with the wide range application of space scales, a larger scale of the simulation is expected to bring out more accurate results.

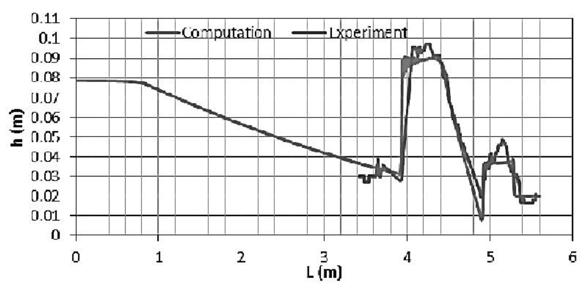
5.2. Episodic time series comparisons of water level between computation and the experiments.

Next, the experimental and computational flows are compared at defferent times, in which the choosen times are t = 1.8 s, t = 3.0 s, t = 3.7 s, t = 8.4 s and t = 15.5 s, respectively. The description of the flow illustrates as following. First, the water flows on the dry channel and once reaching the bump, part of the wave is reflected and forms a bore travelling back in the upstream direction, while the other part moves up the bump, resulting in a wave propagation on an upward dry slope (t = 1.8 s). Then, the water flows on the downward dry slope until arriving in the pool of water at rest, after it was passing the top of the bump. There, the rapid front wave is slowed down abruptly and a bore forms, travelling in the downstream direction (t = 3 s). This bore reflects against the downstream wall and travels back towards the bump, but the water is unable to pass the crest at this time (t = 3.7 s). A second reflection against the downstream wall is needed to enable the wave to pass the bump and to travel back into the upstream direction (t = 8.4 s). Multiple reflections of the flow occur both against the bump and the channel ends (t = 15.5 s).

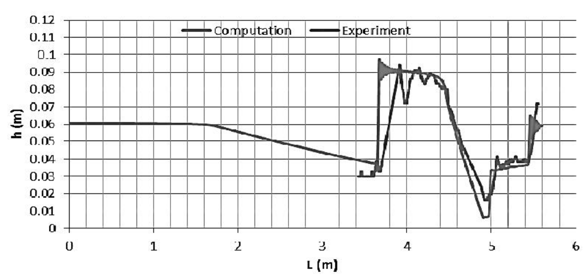
For the water surface profile at t=1.8s (Figure 5(a)), the agreement between the numerical model and the experiment results is quite good except in the distance from L=4.42 m to L=4.76 m where is the down side of the bump. The capable reason for this difference is that the water layer at this time is too thin. In this case, SWASH computational processes may recognizes the presence of water depth as the value of zero. This limitation of the model is expected to be dealt with by re-encoding the model. Figure 5(b) show the water surface at 3 second. The results of the computation and the experiment seem to be the same. There is just a small difference at the beginning of the bump where the computation indicates the more reflected water waves in comparison with that of the experiment. Water surface at 3.7 seconds is indicated in Figure 5(c). The result of numerical is satisfied although the computational result still has several small discrepancies in comparison with that of experimental result. The water before the bump still reflect further than that of experiment. The water level is slightly underestimated by the computation at the end of the bump. In Figure 5(d), at 8.4 seconds, after the bump water surface of the computation is closest to that of experiment. This may be explained by the stable of the flow when the downstream pool was filled up with water and the boundary conditions of the model such as the Courant number, the Manning friction coefficient, and the others were approximately close to the real flow. However, before the bump the computational flow does not express as reflected waves as experimental result. Figure 5(e) illustrates the water surface profile at 15.5 seconds. At this time, although the agreement between computational and experimental result is quite close, there are several small discrepancies appearing at the upstream front of the bump. The water level in numerical result slightly over estimates the experiment. This might cause by the presence of multiple reflections of water waves here. In this case, the various different boundary conditions were applied to the modeling in order to deduce possible causes. However, discrepancies of the results expressed little change. A deep intervention in the WASH source code is expected to bring out a better result.



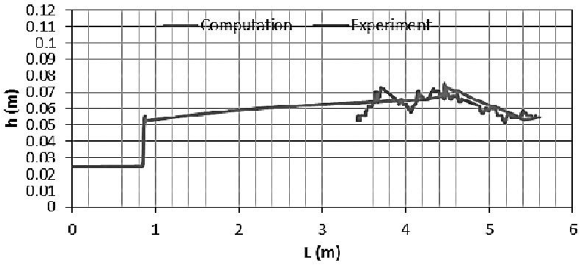
(a) t = 1.8 s



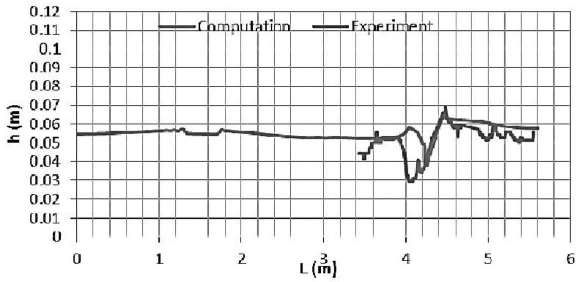
(b) t = 3 s



(c) t = 3.7 s



(d) t= 8.4 s



(e) t= 15.5 s

Figures 5. Episodic time series comparison of water level profile

6. CONCLUSIONS

This study undertakes a validation of SWASH for transformation of dam-break flow over a triangular bottom sill. On the overall, although there are still several small differences in result between the model and experiment, the robustness of SWASH in terms of its skillfulness to simulate flood propagation flows is considerable.The result illustrated that SWASH, in general, reproduced the water flow measured in the experiments, and described the associated processes of propagation considerably well. The computational model was able to capture nearly exact the water level profile observed in the experiments. In addition, the accurate simulation of the propagation process provided a good estimate of measured waves on the real experiment. The result of this computational model still contains several discrepancies in comparison with that of experimental result, in which the main difference is the underestimation of reflected waves in the reproduced flow. A further analysis that takes deeply intervention in the SWASH source code may deal with this problem to produce a more accurate simulation.

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Tóm tắt:

ỨNG DỤNG SWASH MÔ PHỎNG DÒNG CHẢY DO VỠ ĐẬP QUA NGƯỠNG TRÀN MẶT CẮT NGANG TAM GIÁC

Nghiên cứu này áp dụng SWASH, một mô hình thủy động có mã nguồn mở để mô phỏng dòng chảy qua ngưỡng tràn phía hạ lưu có mặt cắt ngang dạng tam giác, trong trường hợp đập chứa nước phía trên bị vỡ. Kết quả của mô hình được so sánh với số liệu thực đo của một thí nghiệm đã được thực hiện bởi S.Soares-Frazão (2007). Nhìn chung, kết quả mô phỏng dòng chảy đo được là khá tốt. Các kết quả của mô hình khớp với thí nghiệm ở cả yếu tố thời gian và quá trình hình thành dòng chảy. Các ước lượng về mực nước, sóng trong quá trình lan truyền được mô tả tương đối chính xác so với kết quả thí nghiệm thực tế. Các sóng phản xạ được tạo ra trong quá trình lan truyền của dòng chảy cũng được ghi nhận rất tốt.

Từ khóa: SWASH, thí nghiệm, mô hình, dòng chảy lũ.

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