SIMULATION OFRIP CURRENTS USING SWASH MODEL

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Abstract: *SWASH model is a relatively new time-domain wave propagation model based on nonlinear shallow water equations with non-hydrostatic pressure. The applicability of SWASH model for simulating rip currents on an artificial barred beach is investigated in this paper. The result shows that the characteristics of rip currents are imitated very well. The distinguishing features of flows on the channels are created quite the same with realistic motion of rip flows.*
Keywords: SWASH, rip current, simulation, wave.

1. INTRODUCTION

Rip currents are strong, narrow offshore flows that return the water carried landward by waves and under certain conditions of near-shore slope and wave activities. Rip currents are extremely dangerous flows because when occurring they can pull surfers or people who are swimming nearby far from the shoreline even these people are the best swimmers. It is estimated that among the surf rescues that occur annually, more than 50% are related to rip currents (Brighton et al, 2013). Rip currents are forced by alongshore variations in wave breaking, in which wave dissipation gradients occur due to the presence of transverse-bar-and-rip morphology (Wright and Short, 1984).Under the wave forcing, increased wave breaking over the bars forces water onshore, generating a hydraulic gradient driving flow towards the rip channel and then offshore. The size, number and location of rip currents are influenced by the ambient wave conditions for these currents serve as a drainage conduit for the water that is brought shoreward and piled up on the beach by breaking waves. In order to produce rip current prediction tools to deduce possible accident as well as advise the public, a number of modeling efforts have been made based on rip current theoretical dynamics.

Several authors used XBeach model to simulate the presence of rip currents and rip channels that have been observed by Google Earth™ and RPAS (remotely piloted aircraft systems) (Guido et al., 2017). The numerical simulations identified the occurrence of a rip current cell circulation in restricted ranges of heights, periods and incident directions. These hydrodynamic conditions, together with the sediment characteristics, were related with the non-dimensional fall velocity parameter, which proved to be an efficient index for the rip current formation. Moreover, the results indicated that the rip current flows did not occur during extreme events; rather they confirm that the flows occurred in medium wave conditions. Before that, COSMOS (Coastal Storm Modelling System) an operational model system was applied to forecast rip currents on Egmond Beach, which were based on a measured data of bathymetry (Christophe et al., 2013). The model produced good estimates of the rip current parameters, which suggested the authors to demonstrate the potential and form of rip current warnings on the beach. Earlier, in another research the rip channel was modelled by two-dimensional wave period averaged

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radiation stress model taken in to account momentum flux (L.K.Ghosh et al 2001). The result indicated that rip current has been simulated quite well.

In coastal area, circulation mainly occurs due to wave and wind induced current. As such two-dimensional model without wave effect fails to simulate the circulation pattern. Recently, the SWASH (Simulating WAves till Shore) code has been developed. It provides 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 environments are allowed. This model has been demonstrated to be capable to model many types of waves and hydrodynamic processes, especially non-hydrostatic, free-surface, rotational flows in two horizontal dimensions. Accordingly, this study conducts a probabilistic rip current forecast model based on the SWASH code to provide several information on the likelihood of hazardous rip currents occurring.

2. COMPUTATIONAL MODEL

SWASH source code has been recently developed by the Delft University. It is a non-hydrostatic wave-flow model in which the NLSW equations are used to predict wave transformation. (Zijlema andStelling, 2005) and (Zijlema et al, 2011) have conducted extensive documents relevant to the numerical framework of SWASH. In addition, in the last papers the authors also discussed about it (Chung et al, 2017). This section just makes a brief outline of numerical procedures concerning to simulating near shore dynamics. The SWASH uses an explicit, second order accurate finite difference method that conserves both mass and momentum at the numerical level for its numerical implementation. The computational grid consists of columns of constant width Δx and Δy in x- and y-direction, respectively, vertically discretized with a fixed number of layers of equal thickness between the fixed but spatially varying bottom and the moving, free surface. Horizontally, a staggered grid is employed for the coupling between velocity and pressure. Consequently, the horizontal velocity u is defined in the central plane of each layer and at the center of each lateral face of the columns as shown in Figure 1, in which the layout of the velocities u, w (indicated by arrows) and the pressure p (indicated by dots) for a vertical cell in case of the standard scheme (on the left), and when the Keller Box is used (on the right). The standard scheme uses a conventional staggered layout in both directions (x and z), whereas for the Keller Box scheme w and p are both located on the layer interfaces (Smit et al. 2013).

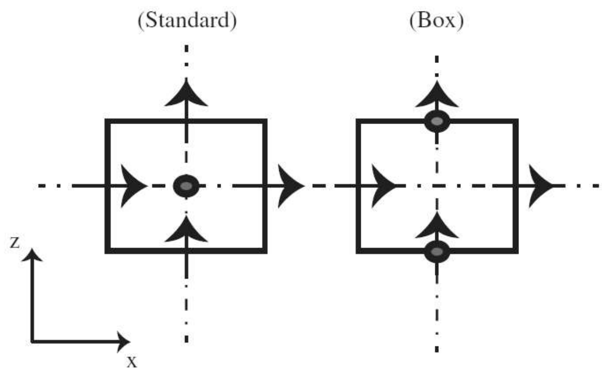


Figure 1. Computational staggered grid between velocity and pressure

In two horizontal dimension of computation, SWASH is governed by the nonlinear shallow water equations as following:

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

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

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

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_z is the still water depth, or downward measured bottom level, $h = \zeta + d$ is the water depth, or total depth, $u(x, y, t)$ 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 (normalised 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.

Appropriate boundary conditions are imposed at the open boundaries of the computational grid domain to solve the system of equations, including: at the offshore boundary, regular or irregular waves are introduced by specifying a local velocity distribution; incoming and outgoing waves are perpendicular to the boundary; the waves are restricted in unidirectional waves; if the onshore boundary is located in the pre-breaking zone, an absorbing condition may be imposed.

3. NEAR-SHORE ZONE TEST CASE AND MODEL SETUP

An artificial near-shore basin is assumed as following. The dimensions of the wave basin are 17.0 m long and 16.0 m wide. The off-shore bar system consists of three sections in which one main section is7.3m long-shore and the two subsections are 3.6 m and 2.5 m, respectively. The longest section is centered in the middle of the basin and the two smaller sections place against the boundary side of the basin. The sections leave two gaps of 1.8 m width located at two sides of the basin that are considered as rip channels. The maximum height of the bar sections is 0.06 m. The bottom width of the bar sections is 1.2 m. The seaward edges of the bar sections were located x = 11.1 m, and their shoreward edges at x = 12.3 m. The topography of the basin has slope bottom of 1:30 extending from the off-shore to the opposite boundary of the basin. The artificial set-up of still water depth is 0.72 m. The artificial incident wave characteristics are assumed as following: wave period T = 1s; wave height H = 0.0475 m. The sketch of the artificial basin is shown in Figure 2. In addition, for this modification of SWASH source code, an important step is to create bottom topography input data based on the initial topography of the artificial basin. On the basic of Akima spline interpolation method (Akima, 1970), a Matlab program is considered as an implement of the model to create the bottom topography.

In terms of model setup, both the initial water level and velocity components are set to zero. The boundary condition at the boundary consists of two parts, the first part defines the boundary side or segment where the boundary condition will be given, the second part defines the parameters. The boundary is one full side of the computational grid. The distance from the first point of the side to the point along the side for which the incident wave spectrum is prescribed is given in ascending order in clockwise. The regular waves to the initial boundary to validate the model is characterized by Fourier series with the amplitude for zero frequency is 0 m; the amplitudes for a number of components are 0.0379 m; the angular frequencies for a number of components are 6.2831853 (rad/s); and the phase for a number of components is 90^0. The computational grid is in a two horizontal-dimensional mode with the grid interval of $\Delta x = \Delta y = 0.05$ m, initial time step of $\Delta t = 0.1$ s. The Manning friction coefficient of $c_f = 0.019$and viscosity factor of Smagorinsky $c_s = 0.2$ are applied. In addition, an effective open boundary is used in the model to eliminate reflective waves so that SWASH can deal with continuous wave trains. For this simulation the Courant number is set in range Cr_{min}=0.2 and Cr_{max}=0.5.The output requests of the computation are conducted in Table and Block type. While the Table files are CSV formatted files. Block files is generated in type of binary files that are analyzed later by several Matlab commands to display the results.

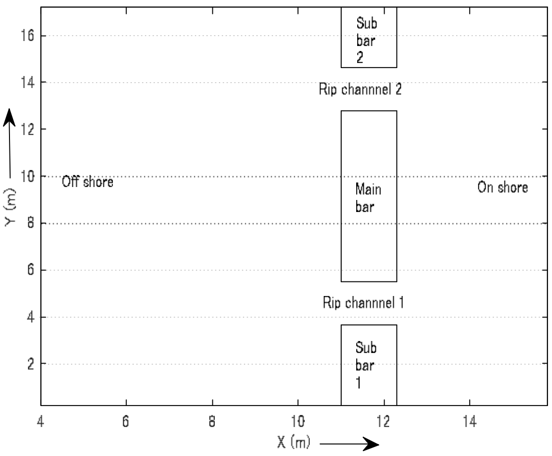


Figure 2. The artificial wave basin

4. RESULTS AND DISCUSSION

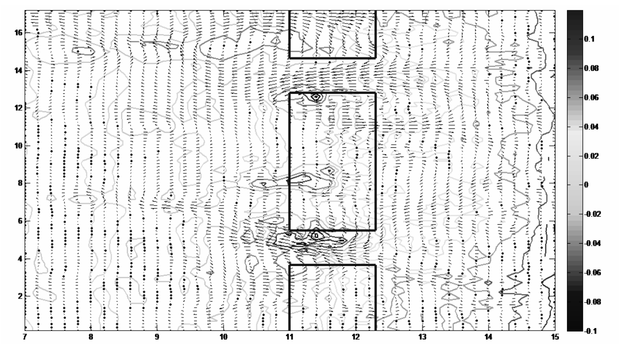


Figure 3. The model of water level

Figure 3 shows the overview of water level elevation. It illustrates that at the onshore region, after breaking circulation the water level is the highest. Offshore of breaking region, the water level is smaller than that of the onshore, in which there is slightly larger wave setdown near the rip channels. Under wave forcing, wave breaking over the bars forces water onshore, generating a hydraulic gradient driving flow towards the rip channels and then offshore. Alongshore wave dissipation gradients occur due to the presence of shallow shore-connected bars alongside deep shore channels.

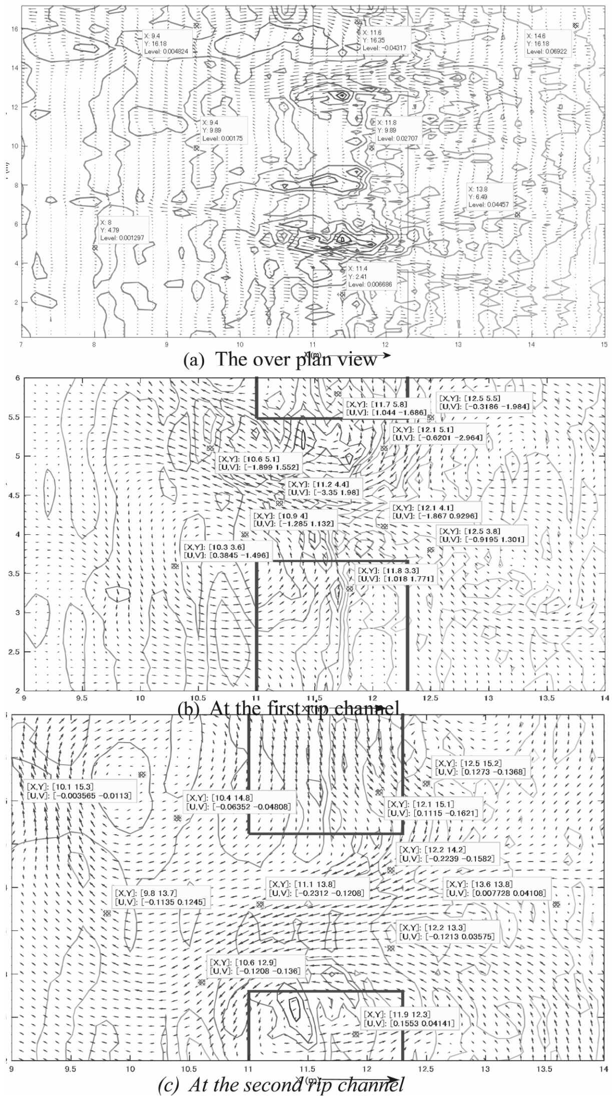


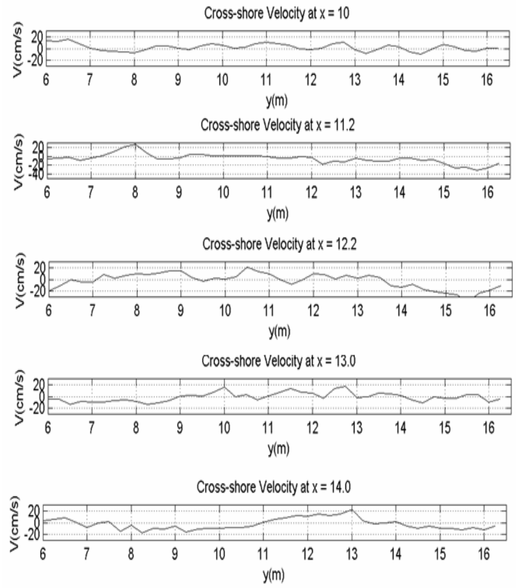
Figure 4. The model of water velocities vector

The presence of rip currents and associated feeder currents is clearly evident in circulation vectors shown in figures 4, in which the cross-shore, and longshore velocities of the computational nearshore zone are presented. The results of model illustrate that the water surface gradients place a strongly influence on to the mean velocities of the cross-shore as well as longshore flows. The current vectors indicate that the presences of strong offshore directed jet in the rip channel and two separate circulation systems are the distinguishing factors of the nearshore circulation. The first circulation includes the classical rip current circulation that encompasses the longshore feeder currents at the base of the rip, the narrow rip neck where the currents are strongest, and the rip head where the current spreads out and diminishes.

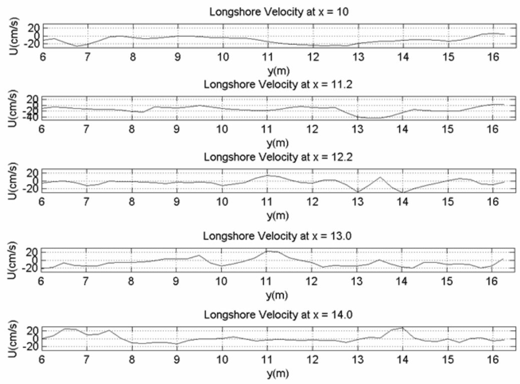
The second system encompasses the reverse flows just shoreward of the base of the rips, in which the waves break at the shoreline driving flows away from the rip channels. This is opposite from the primary circulation. After that the flows are dragged in the feeder currents and returned towards the rip channels. In addition, The presence of the feeder currents illustrate that the mean values of longshore pressure gradients, which are created by the depression in the water surface at the rips, are very large so that they can overcome the traditional longshore radiation stress forcing that always drive the longshore flow in perpendicular direction.

Figures 5 express mean velocities at several cross-shore (Fig. 5a) and longshore (Fig.5b) sections. In the figures, the mean values at section x = 10 describe the characteristics of flows at the seaward edge of the bar systems. The sections x = 11.2 and 12.2 characterize the flows on the crest of bar system at seaward and shoreward, respectively. The section x = 13.0 displays currents at necks of the rip channels. The flows at section x = 14.0 represent for the nearshore feeder currents. In addition, the two rip channels are located at y = [3.6 5.4] and y = [12.7 14.5], respectively. However, for owning the similar features of the rips, this part of the research just examines the characteristics of flows at the second rip channel.

The cross-shore velocity profiles show noticeable asymmetry between two border sides of the rip channel. The asymmetry seem relating to the momentum flux in the feeder currents. The rip shift to one side of the channel when an asymmetry of momentum flux in the opposite feeder currents occurs. The figures also illustrate that the cross-shore rip velocities are decreasing down along the channel. The position of maximum rip velocities almost locate at the neck of channel. The longshore velocities at the boundaries of rip channel also show the same asymmetric feature to the cross-shore velocities. However, it is difficult to characterize location of the maximum longshore velocities. These maximum values vary from section to section. In addition, the longshore as well as cross-shore velocities at the seaward crest of the bar system are vary in the widest range in comparison with that of other sections.



(a) Cross-shore



(b) Longshore

Figures 5. Velocities at several typical cross-shore and longshore sections

Finally, cross-shore profiles of mean wave height over the bar crest (at y = 11.23) and the rip channel (at y = 13.68) are examined as shown in Figure 6. The Figure illustrates the rate of wave height decay in the channel gives some indication as to the strength of the rip current. At y = 11.23, the mean of wave height are decreasing shoreward, in which the significant decrease occurs after the bar crest. At y = 13.68, in the shoreward direction, the mean of wave height slightly increases until the seaward side of the rip channel. After this point, the wave height decrease significantly to the shore.

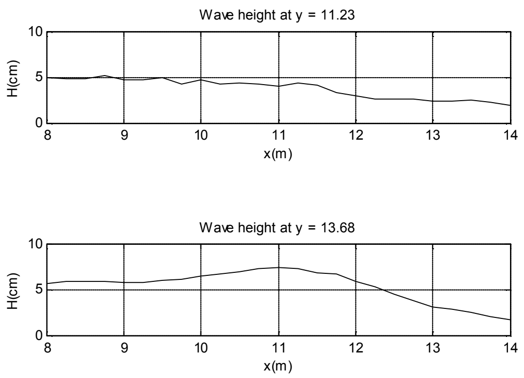


Figure 6. Wave height at several typical sections

5. SUMMARY REMARKS

The SWASH model with non-hydrostatic, free-surface, rotational flows in two horizontal dimensions was used to consider its applicability on simulating rip currents on a barred beach. The result shows that the characteristics of rip currents are imitated very well. The distinguishing features of flows on the channels are created quite the same with realistic motion of rip flows. The water surface gradients place a strongly influence on to the mean velocities of the cross-shore as well as longshore flows. The longshore feeder currents are simulated. The cross-shore as well as longshore velocities profiles show noticeable asymmetry between two border sides of the rip channel. The mean wave heights are also simulated quite good especially over the bar crest and rip channel. Although SWASH simulates rip currents at near-shore zone in this case in a considerable result, the field site experiment however is needed to confirm the accuracy of the model.

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Tóm tắt:

SỬ DỤNG MÔ HÌNH SWASH MÔ PHỎNG DÒNG XA BỜ

SWASH là một mô hình truyền sóng tương đối mới dựa trên các phương trình nước nông thuỷ động phi tuyến. Bài báo này nghiên cứu khả năng ứng dụng của mô hình SWASH trong việc mô phỏng dòng "rip" tại một bãi biển giả lập, có sự tồn tại của các roi cát. Kết quả cho thấy những đặc điểm của dòng "rip" được mô phỏng tương đối chính xác. Các đặc trưng nổi bật của kiểu dòng chảy này được tạo ra khá phù hợp với chuyển động trong thực tế của chúng.

Từ khóa: SWASH, dòng "rip", mô phỏng, sóng.

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