

**APPLICATION OF SWASH ON SIMULATING  
WAVE DECOMPOSITIONS OVER A SUBMERGED BAR****Nguyen Trinh Chung<sup>(1)</sup>, Vu Van Duc<sup>(2)</sup>**

**Abstract:** *Non- hydrostatic numerical model namely SWASH has been used to simulate wave propagations over a submerged bar in a wave flume. Wave characteristics obtained from the model have been compared with experimental results conducted by Ohyama et al (1995). The agreement between model results and the experiments was quite good. The decomposition phenomena of waves were simulated quite the same with the experimental results. Although there are some small discrepancies between computation and experiment, the applicability of SWASH in simulating wave over submerged bars is considerable.*

**Keywords:** SWASH, simulate, wave decompositions, experiment.

**1. INTRODUCTION**

The prediction of wave conditions is always an essential characteristic of coastal engineering. It is especially important for near-shore zones, where the bottom topography places strongly impacts on wave climates. The shallow water waves are influenced by several typical factors such as diffraction, refraction, breaking, shoaling and so on. As a result, the wave heights become comparable to the water depth, and therefore the waves are strongly non-linear. Moreover, nonlinear wave interaction often induces the decomposition phenomenon of a wave train on the lee side of a bar when waves propagate over it. The mechanism of phenomena in which large waves decompose into shorter waves while propagating over a submerged bar has been conducted in some researches. Johnson et al. (1951) have revealed that when waves propagate over natural reefs, the energy is transmitted as a multiple crest system. Beji and Battjes (1993) have indicated that nonlinear interactions transfer wave energy from the leading wave component to higher harmonics that cause the wave form to become steeper, when waves propagate onto the front slope of the bar. On the lee side of the bar, water

depth becomes deep and the nonlinear coupling of the higher harmonics with the fundamental wave becomes weaker, bound higher harmonics are released as free waves, inducing the generation of wave decomposition phenomenon. The dispersive waves after the bar propagate with different phase speeds which lead to a quite complicated process. The research has also indicated that when waves are passing over the bar, the generation of high frequency energy and its transfer among nearly harmonic wave components due to the nonlinear interactions are hardly affected by wave breaking which act merely as a secondary effect by simply re-scaling the wave spectrum through overall energy dissipation. This conclusion implies the feasibility of numerical modeling of the harmonics generation and release in breaking waves on the basis of a physical model for nonlinear non-dissipative wave-wave interaction.

In terms of numerical simulation, one typical approach is to use Stokes-type expansions of velocity potential and water surface elevation, which allows third-order solutions to be successfully derived for relatively simple cases such as wave-wave interaction over a horizontal bottom (Hsu et al., 1979). However, second-order expansions have been employed in mostly numerical models because of mathematical

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difficulties with higher-order formulations. Another approach is based on Boussinesq-type equations, in which the order of wave dispersivity is also assumed to be small and of the same order as the nonlinearity. After the 1990s, the original Boussinesq equation has been improved by many researchers (Nwogu, 1993; Madsen and Soresen 1992; Madsen, 1991) to extend its applicable range, and been used to study the relatively complicated wave transformation. Authors Beji and Battjes conducted a study on numerical simulation of nonlinear wave propagation over a bar (Beji and Battjes, 1994). Other authors tried to predict the decomposition of waves by several numerical models on the basis of fully nonlinear potential theory, Stokes second-order theory, and Boussinesq-type theory (Ohyama and Nadaoka, 1994). Despite all that, after investigating wave evolution during passage over submerged shelf and carrying out the comparisons between numerical results and experimental data, Ohyama et al. (1995) indicated that energy transfer from bound components into free waves in the higher harmonics cannot be accurately evaluated by the Boussinesq-type equations. Later, Gobbi and Kirby simulated wave evolution over submerged sills by a high-order Boussinesq model (Gobbi and Kirby, 1999). Some authors simulated the propagation of cnoidal waves over a submerged bar using a two-equation  $k-\epsilon$  turbulence model, where the free surface is handled by the volume-of-fluid (VOF) method (Y.M.Shen et al, 2004). However, there were several discrepancies between the calculations and experiments for several higher harmonics in the transmitted waves. These authors suggested that a more refined turbulence model may be needed for the simulation of complex wave motions.

In order to accurately simulate the wave propagation over submerged bars, the application of high-dimensional numerical model is inevitable. Recently, Delft University has developed an open source code namely SWASH (Simulating WAVes till Shore). It is a

non-hydrostatic wave-flow model in which the non-linear shallow water (NLSW) equations are used to predict wave transformation. In addition, this model is an implementation of the basic 3D mass and momentum balance of a free surface, incompressible fluid with constant density. It is a software tool that was developed for a very wide range of hydraulic situations. Moreover, emphasis is put on describing hydraulic processes rather than boundary conditions and relations with certain structures. As a result, quite a robust model was built with many applications on wave propagations in coastal zones. Accordingly, this study apply SWASH code to simulate experimental wave propagation over a submerged bar which was resulted of a laboratory experiment conducted by Ohyama et al. (1995).

## 2. COMPUTATIONAL MODEL

SWASH source code has been developed on the basis of a previous code namely SWAN. It is a non-hydrostatic wave-flow model in which the NLSW equations are used to predict wave transformation. Authors Zijlema and Stelling have conducted extensive documents relevant to the numerical framework of SWASH (Zijlema and Stelling, 2005) and (Zijlema et al, 2011). In addition, in the last paper the authors also discussed about this model (Nguyen Trinh Chung et al, 2017). This section makes a brief outline of numerical procedures concerning to wave decomposition phenomena. The most natural and advantageous basis framework for advanced wave modeling in coastal areas which was taken in to by SWASH is an explicit, second order finite difference method for staggered grids. Moreover, in case the momentum conservation is retained in the finite difference scheme, a discretized form of the NLSW equations can automatically be shock-capturing. In vertical direction, the flow should be divided into a fixed number of terrain-following layers, which can be perfectly handled by the computational domain of the

model. In terms of time integration of the continuity and horizontal momentum equations, to maintain the stable conditions of waves against the alteration, the second order leapfrog scheme is adopted. For the advection terms in the horizontal momentum equations, in order to retain second order accuracy in time, the MacCormack predictor-corrector technique is employed. A Poisson equation for the pressure correction is solved to enforce the local mass continuity. This equation steers the non-hydrostatic pressure towards a state at which all mass residuals in the active grid cells become negligible small, reflecting a satisfaction of local mass conservation. At global mass conservation point of view, this element is obtained by solving a depth-averaged continuity equation for the solution of the surface elevation.

Depending on the vertical layout of the pressure points, the pressure gradients in the vertical momentum equations are approximated by means of the Keller Box scheme or central differences. At very low vertical resolution, the Box scheme gives good dispersive properties. At high vertical resolutions the standard layout is preferable because it appears to be more robust while its dispersion characteristics are then usually sufficiently accurate. In the present study simulations with 3 layers and less are done with the Keller-Box scheme.

In one horizontal dimension of computation, SWASH is governed by the equations as following:

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

$$\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + g \frac{\partial \zeta}{\partial x} + \frac{1}{2} \frac{\partial q_b}{\partial x} + \frac{1}{2} \frac{q_b}{h} \frac{\partial(\zeta - d)}{\partial x} + c_f \frac{u|u|}{h} \quad (2)$$

$$= \frac{1}{h} \frac{\partial}{\partial x} (h v_t \frac{\partial u}{\partial x})$$

$$\frac{\partial w_s}{\partial t} = \frac{2q_b}{h} - \frac{\partial w_b}{\partial t} \quad \text{where } w_b = -u \frac{\partial d}{\partial x} \quad (3)$$

$$\frac{\partial u}{\partial x} + \frac{w_s - w_b}{h} = 0 \quad (4)$$

Where  $t$  is time,  $x$  is located at the still water level and the  $z$ -axis pointing upwards,  $\zeta$  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, or total depth,  $u(x, t)$  and  $v(x, t)$  are the depth-averaged flow velocities in  $x$  directions,  $q_b$  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,  $g$  is gravitational acceleration,  $c_f$  is the dimensionless bottom friction coefficient.

### 3. EXPERIMENTS TEST CASES

Ohyama et al (1995) conducted a flume experiment on transformation of wave propagating over a submerged bar. Accordingly, physical model experiments were conducted in a wave flume 65 m in length, 1.0 m in width, and 1.6 m in height. A submerged trapezoidal shelf with the dimension of 0.35 m in height, 2.9 m in width of the bottom, 1.5 m in width of the top was used in the experiment. The submerged trapezoidal shelf was set at the distance of 28.3 m from the piston-type wave generator at one end of the flume. A wave absorber, composed of coarse material, was placed at the other end of the flume. The still water depth was 0.5 m in the deeper region and 0.15 m over the horizontal part of the shelf. The waves and water surface elevations were measured at five different stations (St.1, St.2, St.3, St.4, and St.5) located at 24.85 m, 27.55 m, 29.05 m, 29.75 m, 31.85 m, respectively. Six different conditions were investigated: three different wave periods which referred to as short, intermediate, and long waves with two different incident wave heights which referred to as smaller and larger waves. The more detail of experimental set-up and initial conditions are shown in Figure 1. The harmonic amplitude wave conditions of the

experiment are listed in Table 1. In the table, values of T (the wave period) and H (the wave height) are calculated from the initial wave conditions of the experiment.

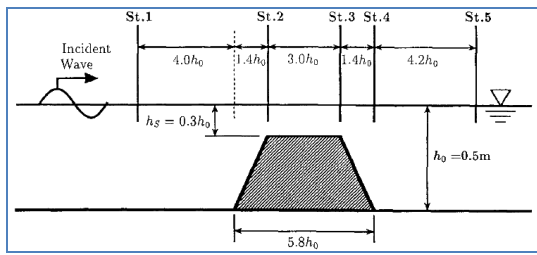


Figure 1. Experimental set-up and initial conditions (modified from Ohyama et al, 1995)

Table 1. Waves conditions

Case	T(s)	H(m)
1	1.34	0.1
2	1.34	0.2
3	2.01	0.1
4	2.01	0.2
5	2.68	0.1
6	2.68	0.2

#### 4. MODEL SETUP

In this paper, the SWASH model is set up to simulate the wave propagation over a submerged bar. The computational grid is in a one-dimensional mode with the grid interval of  $\Delta x = 0.05$  m, initial time step of  $\Delta t = 0.01$  s. Three options for vertical layer of flow are applied in the computation, in which single, two equidistant, and three equidistant layers are considered. The computational bathymetry of the input model is calculated from the parameter bottom flume of the experiment. The simulating wave conditions are conducted by numerical method based on experimental wave conditions. The modeling incident waves are set at the same point where the wave generator was set in the experiment. The computational submerged bar is assumed to be waterproof. The constant friction factor of 0.002 and viscosity factor of 0.005 are applied. An effective open boundary is used in the model to eliminate reflective waves so that SWASH can deal with continuous wave trains.

The initially intent purpose of this research is to test the potential ability of SWASH model in terms of simulating wave decomposition over a submerged bar. Accordingly, in this paper the simulating results at station 3 (St.3) and station 5 (St.5) with high wave conditions (case 2, 4, and 6) of the experiment are presented as shown in Table 2.

Table 2. Simulating cases of the research

Case	T(s)	H(m)
2	1.34	0.2
4	2.01	0.2
6	2.68	0.2

#### 5. RESULTS AND DISCUSSION

As mention in the model setup section, the model was simulated for three different vertical layers to examine the contribution of number of vertical layers in the modeling accuracy. The model results were then compared with that of experiment created by Ohyama et al (1995).

##### 5.1. Comparison of wave profile at station3.

Figures 2 and 3 compare the numerical results (for single, two, and three equidistant vertical layers) which are obtained from the SWASH model and the measured result of wave profiles at Station 3 in three different cases of wave conditions including case, 2, 4, and 6. In the figures, in order to adjust the phase between the computational and measured profiles, the time series  $t'$  (s) has been defined as the time elapsed from the instant at which the surface elevation at Station 1 was zero. Other parameters include  $\eta$  (m); H (m); T (s) in which  $\eta$  is the water surface elevation, H is the corresponding input wave height, and T is the corresponding input wave period. In general, the agreement between computation (all three layer options) and measurement are satisfied. The Figure shows that the wave crests are steep. This can be explained by the augmentation of wave nonlinearity while passing onto the up slope of the bar. The wave height increases and reaches the highest value on the top of the bar. In case 2, there was almost no difference in both

computational and experimental results, but the slightly lower value at the peak of waves. In this case, the flat troughs created by SWASH were obviously similar to the experimental result. In case 4, the result of SWASH model is acceptable, although there were still several small differences in comparison with the result of experiment. A very steep primary crest followed by a small hump was created in both numerical and measured results. The slightly discrepancy between them was that the highest value of water elevation in the experiment is approximately 1.45, and the lowest is -0.40, while these value in SWASH results were 1.35 and -0.35, respectively.

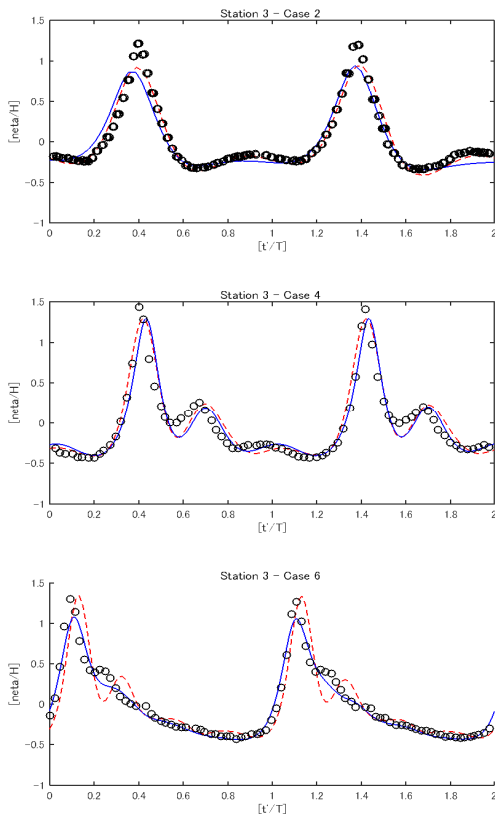


Figure 2 Comparison of wave decomposition at station 3 between experiment (o black) and different options of model, 1 layer (-- red), 2 layers (- blue)

In case 6, the wave profile obtained by numerical model was significantly considerable although it seemed slightly different in comparison with result of measurement. In the SWASH result, with one layer option, a very steep primary crest followed by a small

hump, where as a pitched-forward profile with gently sloping tails was observed in the experiment. This discrepancy was reduced in the model option of two and three layers. However, one layer option simulated the water elevation more closely to the experiment in comparison with other options of layers. Moreover, SWASH indicated deeper troughs than the measured profiles. In addition, excluding the result of single layer option in case 6, the computational wave crests were slightly underestimated in comparison with the measurement of experiment. The underestimation might be improved by applying an appropriated horizontal mesh grid in to the model.

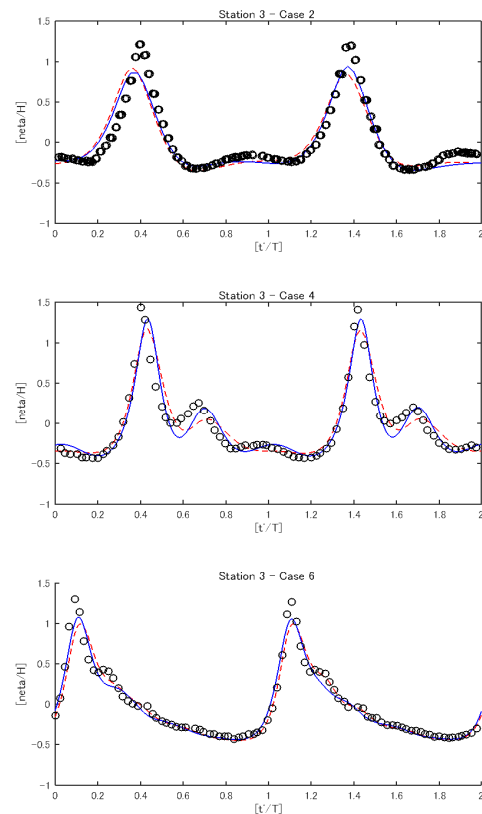


Figure 3 Comparison of wave decomposition at station 5 between experiment (o black) and different options of model, 3 layers (-- red), 2 layers (- blue)

## 5.2. Comparison wave profiles at station 5

Next, the simulating waves of three layer model options were compared with the waves of experimental result as shown in Figure 4 and 5.

With two and three layer options of the model, the wave amplitudes were quite the same in both numerical and experimental results. After passing over the bar, wave nonlinearity becomes weak with the growth of water depth so that the free higher harmonics are created from the bound higher harmonics. Due to dispersive wave, each higher harmonic propagates with its own phase speed that lead to a significant change of wave profiles. The decomposition phenomenon of wave has occurred in which two waves were in formed from one primary wave.

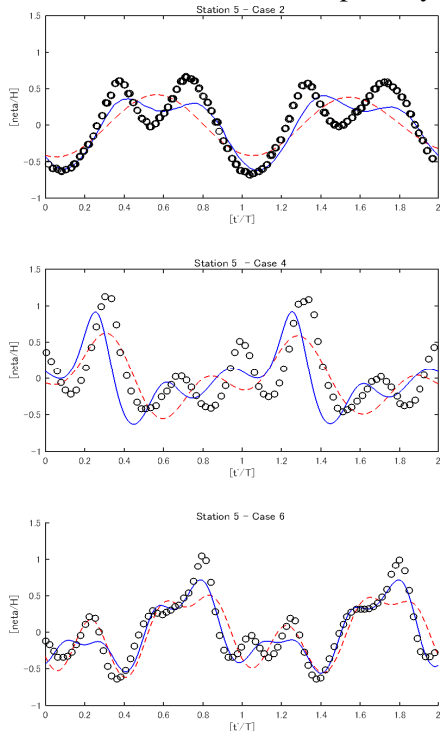


Figure 4 Comparison of wave decomposition at station 5 between experiment (o black) and different options of model, 1 layer (-- red), 2 layers (- blue)

Especially in case 6, the incident waves were long waves so that the wave decompositions were really drastic. Although the waves that created by SWASH model made a considerable agreement with experimental results, there were some small discrepancies. In all cases (2, 4 and 6), the model slightly underestimated the wave profile behind the bar. In case 2 and 6, the shapes of the modeling elevated waves were acceptable, while in case 4, the wave's crests were steeper than that of the measurement. In

addition, in case 4, while the modeling waves of the two layer option expressed slightly faster decomposition, the three layer option simulated slower waves in comparison with that of the experiment. In the single layer option of computational model, the result expressed several discrepancies. Particularly in case 2, the decomposition phenomenon of wave has not occurred as shown in the experimental result. In other cases, the decompositions were also not as clear as expectation. Moreover, in case 4 the modeling wave decomposed slightly slower than that of the experiment.

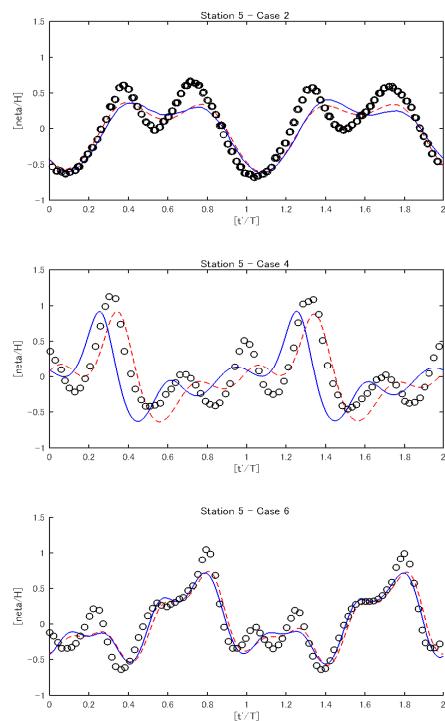


Figure 5 Comparison of wave decomposition at station 5 between experiment (o black) and different options of model, 3 layers (-- red), 2 layers (- blue)

## 6. SUMMARY REMARKS

The SWASH model with non-hydrostatic pressure formulation was used in three different vertical layer options to examine its applicability in simulating wave propagation over a submerge bar. The agreements between model results and the experiments were quite good. The decomposition phenomena of waves were simulated quite the same with the

experimental results. However, there were some small discrepancies between computation and experiment. The model slightly underestimated the wave profile. The shapes of the modeling elevated waves had several differences. In some cases, the decomposition phenomena were simulated slightly slower/faster than that of the experiment. At the top of the bar (station 3), there was no differences in wave propagation among single, two and three layer options of the computation. In contrast, behind the bar (station 5) the single layer option of the model expressed a significant difference with the other options as well as the experiment in terms of decomposition. This

demonstrates that an appropriate vertical layer plays an important role in the accuracy of the SWASH model. In this study, the computational results illustrated that for two and three equidistant vertical layers, the model simulated the wave propagation quite good. For the single vertical layers, the simulating wave result seemed to be under expectation.

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**Tóm tắt:**

**ỨNG DỤNG SWASH MÔ PHỎNG HIỆN TƯỢNG SÓNG  
PHÂN TÁCH KHI LAN TRUYỀN QUA MỘT CÒN NGẦM**

*Mô hình số thủy động SWASH được sử dụng để mô phỏng sự lan truyền sóng qua một cồn ngầm của một thí nghiệm trên máng sóng. Các đặc điểm của sóng thu được từ mô hình được so sánh với kết quả thực nghiệm được tiến hành bởi Ohyama và các cộng sự (1995). Sự tương đồng của kết quả mô hình và thí nghiệm tương đối tốt. Hiện tượng phân tách của sóng được mô phỏng gần như hoàn toàn giống với các kết quả thực nghiệm. Mặc dù có một số khác biệt nhỏ, nghiên cứu đã chỉ ra khả năng áp dụng của SWASH trong việc mô phỏng sóng lan truyền qua cồn ngầm là rất đáng kể.*

**Từ khóa:** SWASH, hiện tượng sóng phân tách, cồn ngầm, thí nghiệm, mô phỏng.

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