Computation of properties of breaking and post-breaking waves on slopes by coupling of BEM and VOF models

Christophe Lachaume[1], Stéphan T. Grilli[2], Phillippe Fraunié[1] and Stéphan Guignard[3]

1. LSEET, Univ. de Toulon et du Var, BP 132, F-83957 La Garde, France
2. Ocean Engng. Dpt., Univ. of Rhode Island, Narragansett, RI 02882, USA (grilli@oce.uri.edu)
3. ESIM, Marseille, France.

1 Introduction

Boundary Element models (BEM) solving fully nonlinear potential flow equations (FNPF) have proved very efficient and accurate for calculating wave shoaling over arbitrary bottom topography, up to overturning of a wave crest (e.g., Grilli and Subramanya, 1996; Grilli *et al.*, 1997). When impact of a breaker jet occurs on the free surface, however, such models break down due to the violation of governing equations (e.g., Fig. 1, curve f).

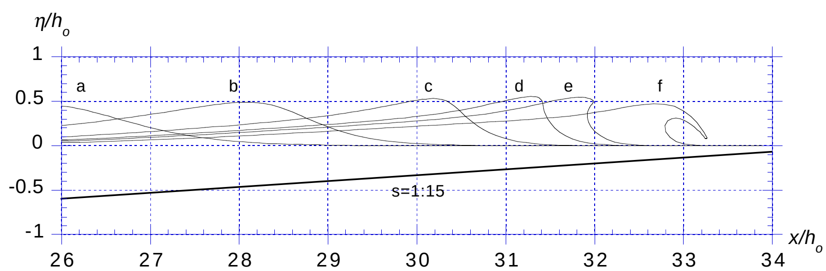

Fig. 1 : Shoaling and breaking of a solitary wave with $H_o/h_o = 0.45$, over a 1:15 slope in the BEM-FNPF model by Grilli *et al.* (1997).

Improvements in computer power have recently led to an increasing use of models based on the Volume Of Fluid (VOF) method, which solve Navier-Stokes equations for free surface flow problems (Guignard et al., 2001). Such models can solve equations on a grid covering the whole (air/water) fluid domain (unlike the BEM which only discretizes boundaries), and are able to accurately follow the motion of free surfaces and interfaces between fluids, represented by segments. VOF models also allow for air to be trapped within the fluid domain and for pieces of water to detach from the main computational domain. Hence, they are ideally suited for modeling breaking and post-breaking waves over a sloping bottom. VOF models, however, are computationally expensive and suffer from numerical diffusion, leading to artificial loss of wave energy (and elevation) over long distances of propagation.

In the present study, the key features and advantages of both BEM and VOF methods are exploited, by coupling these methods to perform two-dimensional wave shoaling and breaking computations (Fig. 2). The BEM method accurately and efficiently models wave shoaling over a sloping bottom, before breaking occurs. The VOF method calculates breaking and post-breaking waves at the top of the sloping bottom, on a refined local grid. Only solitary waves propagating over plane slopes are considered here. Two types of coupling methodologies are implemented. In the first one, referred to as "weak coupling", the wave is propagated in the BEM domain, up to close to the breaking point, into a smaller region at the top of the slope, representing the VOF domain.

Lateral (offshore) boundary conditions and internal velocity and pressure fields are then computed with the BEM, at the VOF grid cell centers, and computations are pursued in the VOF domain (Fig. 2). More details regarding this approach can be found in Guignard et al. (1999).

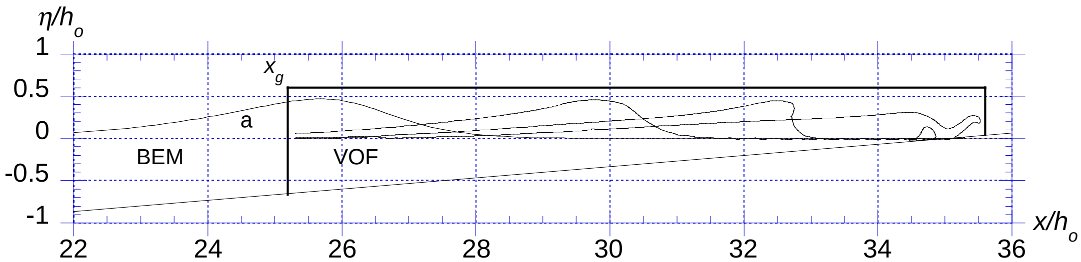

Fig. 2 : Principle of weak BEM/VOF model coupling. Shoaling of a solitary wave with incident height $H_o/h_o = 0.45$, over a 1:15 slope (curve a). Fluid velocities and pressures are calculated at a vertical gage at x_g and in VOF box. VOF model is initialized with wave a, and uses lateral BEM boundary conditions at x_g.

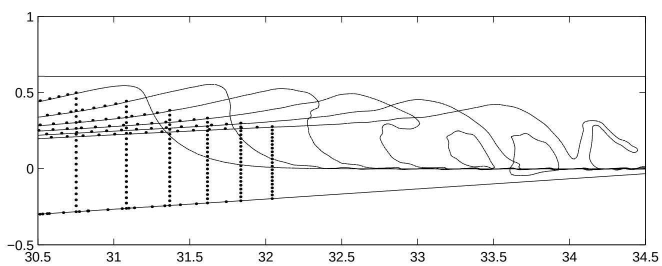

Fig. 3 : Principle of strong BEM/VOF model coupling. Same case as in Fig. 2. (—–) VOF results; (•) BEM nodes.

In the second method, referred to as “strong coupling”, a moving vertical matching boundary is used to specify/exchange boundary conditions in between both models, within a fluid region where both models overlap (Fig. 3). Although both of these methods provide similar results for solitary waves, the second method makes it possible modeling periodic or irregular waves. This will be left out for future work. In the present study, we will the “weak coupling method” to the computation of properties, essentially shape and kinematics, of solitary waves breaking over plane slopes.

2 Results

As a first example of results of model coupling, the shoaling and breaking of a solitary wave of initial height $H_o/h_o = 0.45$ is calculated over a 1:15 slope. This case, which leads to a large scale plunging breaker, was modeled by Grilli *et al.* (1997) with the BEM, up to impending jet impact (Fig. 1). Li and Raichlen (1998) compared these FNPF computations to detailed laboratory experiments and showed a good agreement up to the stage of curve f. Figs. 2 and 3 show results of the BEM-VOF model for this case, for weak and strong coupling, respectively; in the second case, the VOF grid has 825 by 80 cells in the x and y directions, respectively. The breaker jet impact occurs in very shallow water, which leads to air trapping and to a rebound creating a new, forward moving, jet. Such features are well observed in laboratory experiments. Fig. 3 shows a comparison of the change in wave height H/H_o, calculated as a function of x/h_o in both BEM and BEM-VOF models, with Li and Raichlen's experiments. Both models agree well with each other, and with the experiments, up to the stage of curve f in Fig. 1 ($x/h_o = 32.7$). Beyond that, the BEM-FNPF model quickly fails; but the agreement of the VOF-BEM model with experiments can still be considered as quite good (considering the experimental variance). This indicates that the VOF method is accurate for modeling post-breaking waves.

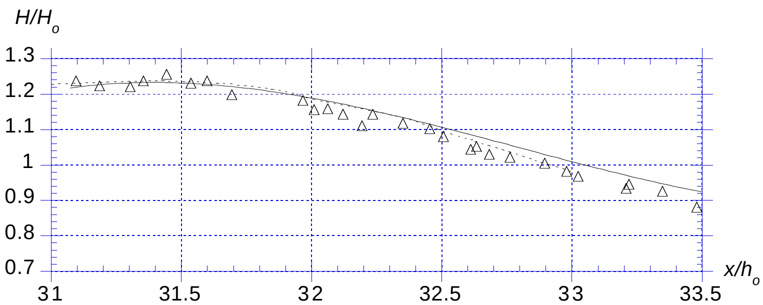

Fig. 4 : Cases of Figs. 1,2,3. (- - - - -) BEM results (Grilli *et al.*, 1997); (——) VOF results; ($\triangle$) Li and Raichlen's (1998) experiments.

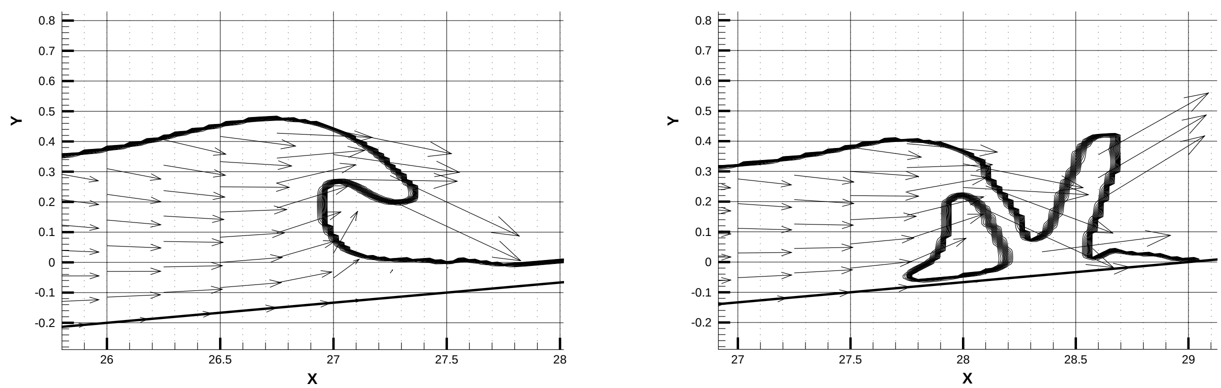

Fig. 5 : Weak BEM/VOF coupling computation of a solitary wave of height $H_o/h_o = 0.5$ breaking over a 1:15 slope: Two snapshots.

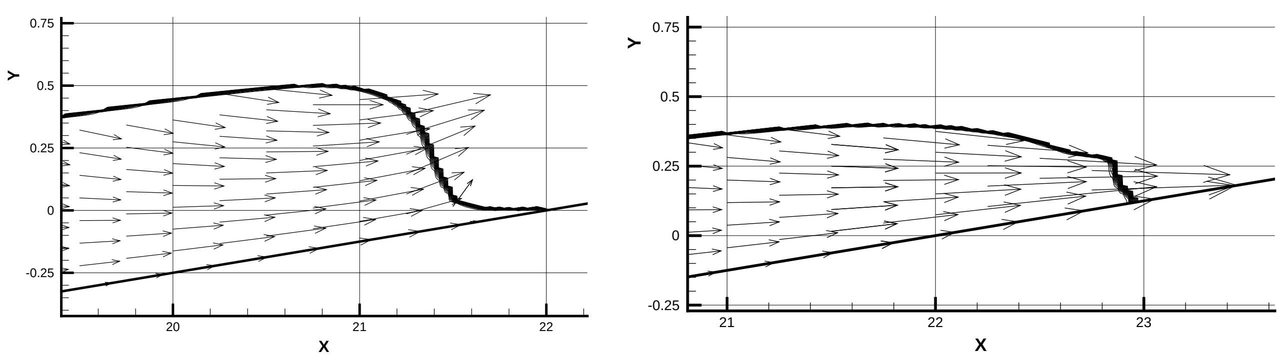

Fig. 6 : Weak BEM/VOF coupling computation of a solitary wave of height $H_o/h_o = 0.5$ breaking over a 1:8 slope: Two snapshots.

The weak BEM-VOF coupling modeling methodology is now used to compute various cases of solitary wave breaking over slopes. All of these results correspond to a wave with initial height $H_o/h_o = 0.5$. We first look at detailed results for a slope 1:15. Fig. 5 shows the development, impact, and rebound of a large plunging breaker, with an enclosed air pipe. By contrast, Fig. 6 shows the propagation and breaking of a wave of identical characteristics over a 1:8 slope. Here, we see the formation of a surging breaker, which runs up the slope as a jet of reducing thickness. Grilli et al. (1997) computed cases similar to Figs 5 and 6 using their BEM model. Computations, however, broke down at jet impact in the first case or during runup in the second case. The present computations have no such limitations and thus allow to compute characteristics of breaking waves on slopes, including maximum runup.

More cases will be shown and discussed during the workshop.

3 References

1. Grilli, S.T. and Subramanya, R., Numerical modeling of wave breaking induced by fixed or moving boundaries. *Computational Mech.*, **17**, 374-391, 1996.

2. Grilli, S., Svendsen, I.A. and Subramanya, R., Breaking Criterion and Characteristics for Solitary Waves on Slopes. *Journal of Waterway Port Coastal and Ocean Engineering* **123** (3), 102-112, 1997.

3. Guignard, S., Marcer, R., Rey, V., Kharif, Ch., and Ph. Fraunié, Solitary Wave Breaking on Sloping Beaches : 2D two-phase Flow Numerical Simulation by SL-VOF Method. *Eur. J. Mech. B-Fluids,* **20**, 57-74, 2001.

4. Guignard, S., Grilli, S.T., Marcer, R. and Rey, V., Computation of shoaling and breaking waves in nearshore areas by the coupling of BEM and VOF methods. In *Proc. 9th Offshore and Polar Engng. Conf.* (ISOPE99, Brest, France, May 1999), Vol. III, 304-309, 1999.

5. Li, Y. and F. Raichlen, Breaking criterion and characteristics for solitary waves on slopes — Discussion. *J. Waterways Port Coastal Ocean Engng.* **124**(6), 329-333, 1998.