

# SPH NUMERICAL SIMULATIONS OF WAVE BREAKING OVER A BARRED BEACH

Pietro Scandura, University of Catania, [pietro.scandura@unict.it](mailto:pietro.scandura@unict.it)  
Corrado Altomare, Politecnical University of Catalonia, [corrado.altomare@upc.edu](mailto:corrado.altomare@upc.edu)  
Ivan Cáceres, Politecnical University of Catalonia, [i.caceres@upc.edu](mailto:i.caceres@upc.edu)  
Giacomo Viccione, University of Salerno, [gviccion@unisa.it](mailto:gviccion@unisa.it)  
Dominic van der A, University of Aberdeen, [d.a.vandera@abdn.ac.uk](mailto:d.a.vandera@abdn.ac.uk)

## INTRODUCTION

The coastal region is one of the most densely populated areas in the world and home to important economic activities, but it is particularly vulnerable to erosion and flooding, which is expected to become more severe due to rising sea levels and more frequent storms. In this scenario, the understanding of coastal hydrodynamics and the availability of reliable hydrodynamic models are crucial for the design of effective coastal defense measures. In particular, more in-depth studies are needed on the hydrodynamics of the surf zone, which plays a crucial role in nearshore erosion and sedimentation processes but is not yet fully understood.

Nearshore bars are common morphodynamic features on most sandy beaches and are known to strongly influence wave breaking and the hydrodynamics in the surf zone. However, most of the studies over the last few decades focused on the idealized case of a plane sloping beach.

In the past several mathematical models have been developed to describe the hydrodynamics of the surf zone. These include models based on the Boussinesq approximation (Tuesser et al. 2012), large eddy simulation models (Zhou et al. 2017), and models based on the Reynolds Averaged Navier-Stokes equations (Jacobsen et al. 2014). All these models are based on the Eulerian description of flows, which results in the discretised form of the governing equations being defined on a fixed grid. This can be a shortcoming of these models, especially when the water/air interface is subject to severe deformations. Lagrangian models are more suitable than Eulerian models for solving the governing equations in the presence of highly deformed free surfaces as occurs during wave breaking.

One of the most developed Lagrangian approaches to fluid mechanics is the Smoothed Particle Hydrodynamic (SPH) method, which has demonstrated the ability to correctly resolve fluid dynamic phenomena involving free surfaces undergoing large deformations (Dalrymple and Rogers, 2006, Crespo et al. 2017). The method has also been used to simulate wave breaking on a flat beach (Makris et al. 2016) and, more recently, wave breaking on a barred beach by Altomare et al. (2023).

Experimental measurements of regular wave breaking on a barred beach were performed by van der A et al. (2017), while van der Zanden et al. (2019) investigated breaking of wave groups.

Here we present SPH numerical simulations of wave breaking on a barred beach in a large-scale wave flume and compare the numerical results with experimental measurements.

## SPH MODEL SET-UP AND RESULTS

A weakly compressible SPH numerical model called DualSPHysics is used in this study (Domínguez et al.,

2021). The fluid domain is discretized into many material particles characterized by position, mass, density, pressure, velocity and acceleration. Each particle interacts with neighboring particles that fall within a radius or smoothing length denoted as  $h_{sph}$ . The contribution of each particle to this interaction is weighted by a kernel function. In DualSPHysics it is possible to introduce an artificial viscosity into the momentum equation (Monaghan, 1992), the magnitude of which can be controlled by the value of a parameter  $\alpha$ , called the artificial viscosity coefficient. Surface waves have been generated using boundary particles that move to replicate the motion of a wave paddle. The simulations were carried out in 2-D initially placing all the particles on a  $dp \times dp$  square grid. The parameter  $coefh = h_{sph}/(dp\sqrt{2})$  shows how large  $h_{sph}$  is relative to the initial interparticle distance  $dp$ .

The experimental data were obtained during a previous experimental campaign carried out in a large-scale wave flume 100 m long, 3 m wide and 5 m deep. Regular waves, with a period of 6 s and a height of 0.55 m, were generated. The waves, after shoaling along the slope of the beach, broke as a plunging breaker.

Free surface elevations were measured using resistive and acoustic wave gauges and pressure sensors, while velocity measurements were taken using an acoustic Doppler velocimeter and two laser Doppler anemometers.

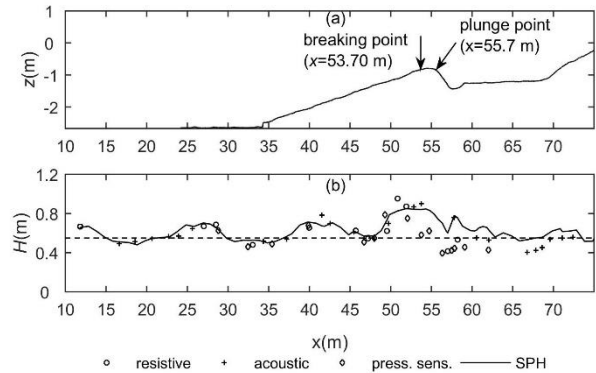


Figure 1 - (a) Longitudinal profile of the wave flume, (b) trend of the wave height  $H$  along the flume.

The results of preliminary simulations were used to determine the set of the SPH parameters that gave the best trade-off between accuracy and computational cost. The values of these parameters are as follows:  $\alpha=0.028$ ,  $dp=0.01$  m and  $coefh=1.3$ .

Figure 1a shows the longitudinal profile of the wave flume

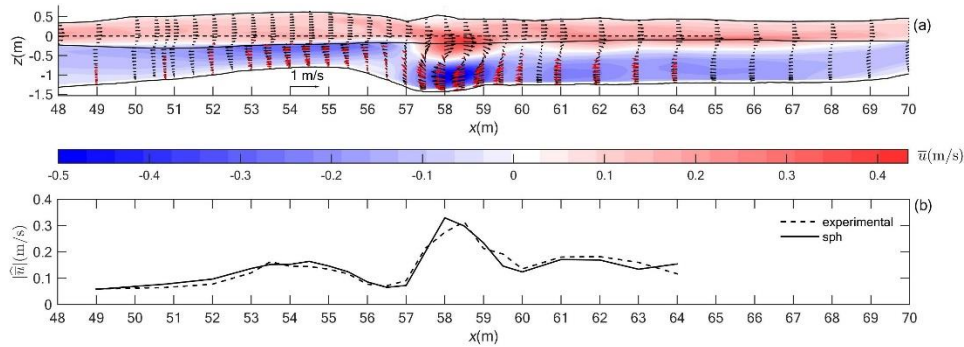


Figure 2 - (a) Time averaged velocity distribution. Red arrows: experiments; black arrows: SPH. (b) Average along the vertical of the time averaged horizontal velocity  $\bar{u}$  for the positions where experimental data are available.

The breaking point is where the wave front becomes vertical, while the plunging point is where the plunging jet hits the free surface. Figure 1b shows the trend of the averaged wave heights. Offshore from the breaking point, there is a fairly good agreement between experiments and the SPH simulation. Here the oscillation in the wave height are due to wave reflection, which was estimated to be 20%. The maximum wave height at the breaking point is predicted quite accurately by SPH, but further onshore the wave height is over-predicted. This may be due to a difference in the definition of the free surface between the SPH and the instruments, but it should be noted that there are also differences between the instruments. In particular, at  $x=57.78$  m, the SPH wave height is close to that measured by the acoustic instrument, but quite far from that provided by the resistive instrument and by the pressure sensor.]

In general, resistive and pressure transducers do not detect localized splashes due to their operating principle, whereas the acoustic transducer, which measures from above, is expected to perform much better in this respect. This may explain the better agreement between SPH and acoustic wave gauges in the surf zone compared to the other instruments.

The mean velocity generated by the waves plays an important role in the transport phenomena that occur in the coastal region, so knowledge of the spatial distribution of the mean velocity is of particular interest. Figure 2a shows the time-averaged velocity distribution. The upper black lines show the positions of the wave crests and troughs. Offshore from the breaking area, the onshore flux is contained between the crests and the troughs while in the breaking region it extends even below the trough level. The most prominent feature of the mean velocity distribution is a recirculating flow above the bar trough, induced by the plunging jet. This hydrodynamic feature is thought to be an important contributor to the scour in front of the onshore face of the bar and to the growth of the bar itself. Figure 2b shows a comparison between the numerical and experimental spatially averaged velocity, from which it can be concluded that there is a fairly good agreement between SPH and experiments.

#### REFERENCES

van der A, D.A., van der Zanden, J., O'Donoghue, T., Hurther, D., Cáceres, I., McLelland, S.J., Ribberink, J.S.

(2017) Large-scale laboratory study of breaking wave hydrodynamics over a fixed bar, *J. Geophys. Res. Oceans*, vol. 122, pp. 3287-3310.

Altomare, C., Scandura, P., Cáceres, I., van der A, D.A., Viccione, G. (2023) Large-scale wave breaking over a barred beach: SPH numerical simulation and comparison with experiments, *Coastal Engineering*, vol. 185, 104362.

Crespo, A., Altomare, C., Domínguez, J., González-Cao, J., Gómez-Gesteira, M., (2017) Towards simulating floating offshore oscillating water column converters with smoothed particles hydrodynamics, *Coastal Engineering*, vol. 126, pp. 11-26.

Dalrymple, R.A., Rogers, D.B., (2006) Numerical modelling of water waves with the SPH method, *Coastal Engineering*, 53 (2), pp. 141-147.

Domínguez, J.M., Fourtakas, G., Altomare, C., Canelas, R.B., Tafuni, A., García-Feal, O., Martínez-Estévez, I., Mokos, A., Vacondio, R., Crespo, A.J.C., Rogers, B.D., Stansby, P.K., Gómez-Gesteira, M. (2022) DualSPHysics: from fluid dynamics to multiphysics problems, *Comp. Part. Mech.*, vol. 9 (5), pp. 867-895.

Jacobsen, G.N., Fredsøe, J., Jensen, J.H. (2014) Formation and development of a breaker bar under regular waves. Part 1: Model description and Hydrodynamics, *Coastal Engineering*, vol. 88, pp. 182-193.

Makris, C.V., Memos, C.D., Krestenitis, Y.N. (2016) Numerical modelling of surf zone dynamics under weakly plunging breakers with SPH method, vol. 98, pp. 12-35.

Monaghan, J.J. (1992) Smoothed particle hydrodynamics, *Annual Review of Astronomy and Astrophysics*, vol. 30, pp. 543-574.

Tiesser, M., Bonneton, P., Marche, F., Chazel, F., Lannes, D. (2012) A new approach to handle wave breaking in fully nonlinear Boussinesq models, *Coastal Engineering*, vol. 67, pp. 54-66.

van der Zanden, J., van der A, D.A., Cáceres, I., Larsen B.E., Fromant, G., Petrotta, C., Scandura, P., Li, M. (2019) Spatial and temporal distributions of turbulence under bichromatic breaking waves, *Coastal Engineering*, vol. 146, pp. 65-80.

Zhou, Z., Hsu, T.J., Cox, D., Liu, X. (2017) Large eddy simulation of wave breaking induced turbulent coherent structures and suspended sediment transport on a barred beach, *J. Geophys. Res. Oceans*, vol. 122 (1), pp. 207-235.