ICCE 2018
36TH INTERNATIONAL CONFERENCE ON COASTAL ENGINEERING 2018
Baltimore, Maryland | July 30 – August 3, 2018
The State of the Art and Science of Coastal Engineering

Numerical Modelling of Kinematics and Dynamics of Spilling and Plunging Breakers in Shallow Waters

Mayilvahanan Alagan Chella and Hans Bihs

NTNU

UNIVERSITY OF NOTRE DAME

Mayilvahanan Alagan Chella

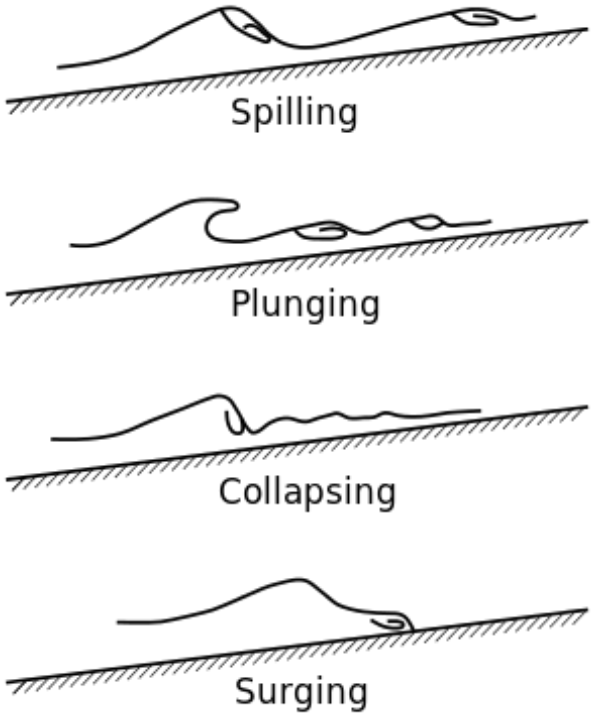
Postdoctoral Research Associate

Department of Civil and Environmental Engineering and Earth Sciences

University of Notre Dame, Indiana, USA

Introduction

- CFD modeling of breaking waves
- Waves in shallow water
  - Shoaling and breaking waves
  - Wave height evolution up to the breaking point
  - Wave height attenuation after breaking
- Breaker types
  - Wave shape at breaking
  - Surf similarity parameter $\xi_0 = \frac{m}{\sqrt{H_0/L_0}}$ (m=slope)
- Large scale flow features



Numerical model: REEF3D

- Developed at the Marine Civil Engineering Group, Department of Civil and Environmental Engineering, NTNU Trondheim
- Two-phase model on finite difference frame work
- Reynolds-averaged Navier-Stokes Equations

$$\frac{\partial u_i}{\partial x_i} = 0$$

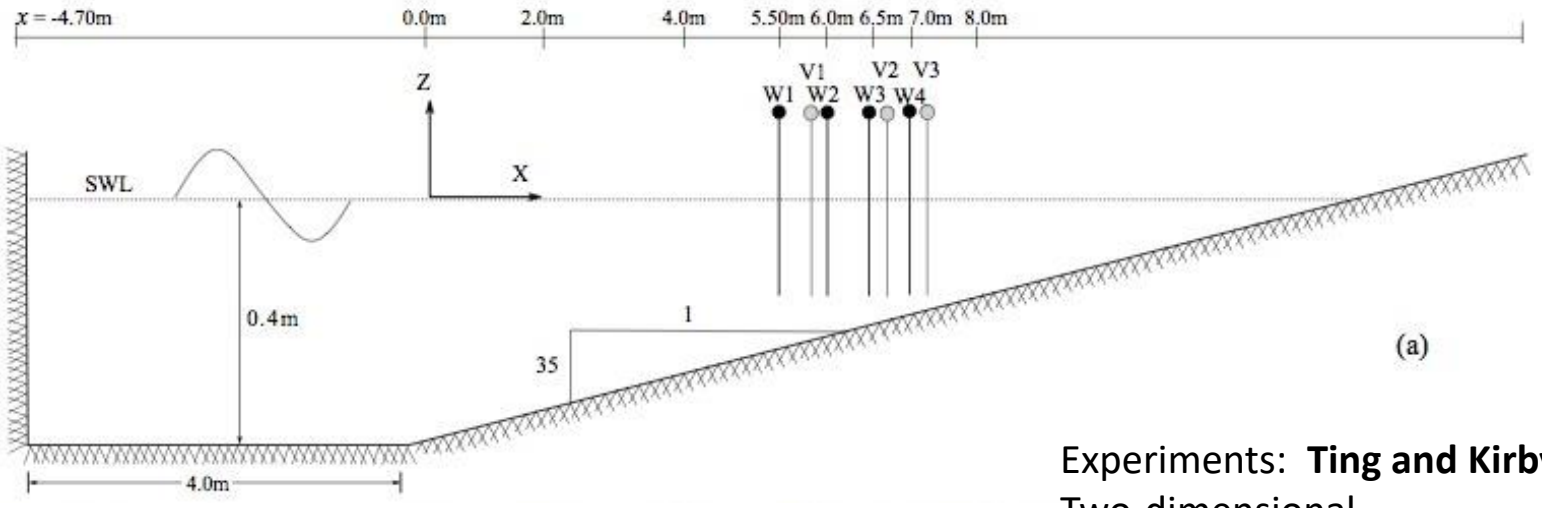
$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left[(\nu + \nu_t)\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right] + g_i$$

- Discretization methods
  - 5th order WENO (Weighted Essentially Non-Oscillatory) scheme
  - 3rd order TVD (Total Variance Diminishing) Runge-Kutta scheme

Numerical model: REEF3D

- Cartesian grid with immersed boundary method
- Staggered grid arrangement
- Adaptive time-stepping method
- k-ω turbulence model (Wilcox, 1994)
- Level set method
  - The level set function is reinitialized after each time step to ensure mass conservation:
  - a PDE based reinitialization scheme (Sussman et al., 1994)
- Parallelization :
  - Domain decomposition approach and Message Passing Interface (MPI)

Numerical setup



Experiments: **Ting and Kirby (1996)**
Two-dimensional
5th order cnoidal waves
Grid size *dx*=0.005m
Wave generation: Relaxation method

Spilling breakers

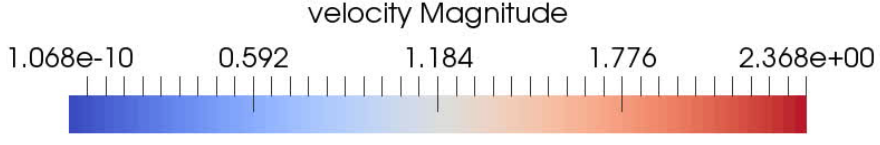
Wave Height H_0= 0.127m
Wave period T= 2.0s

Plunging breakers

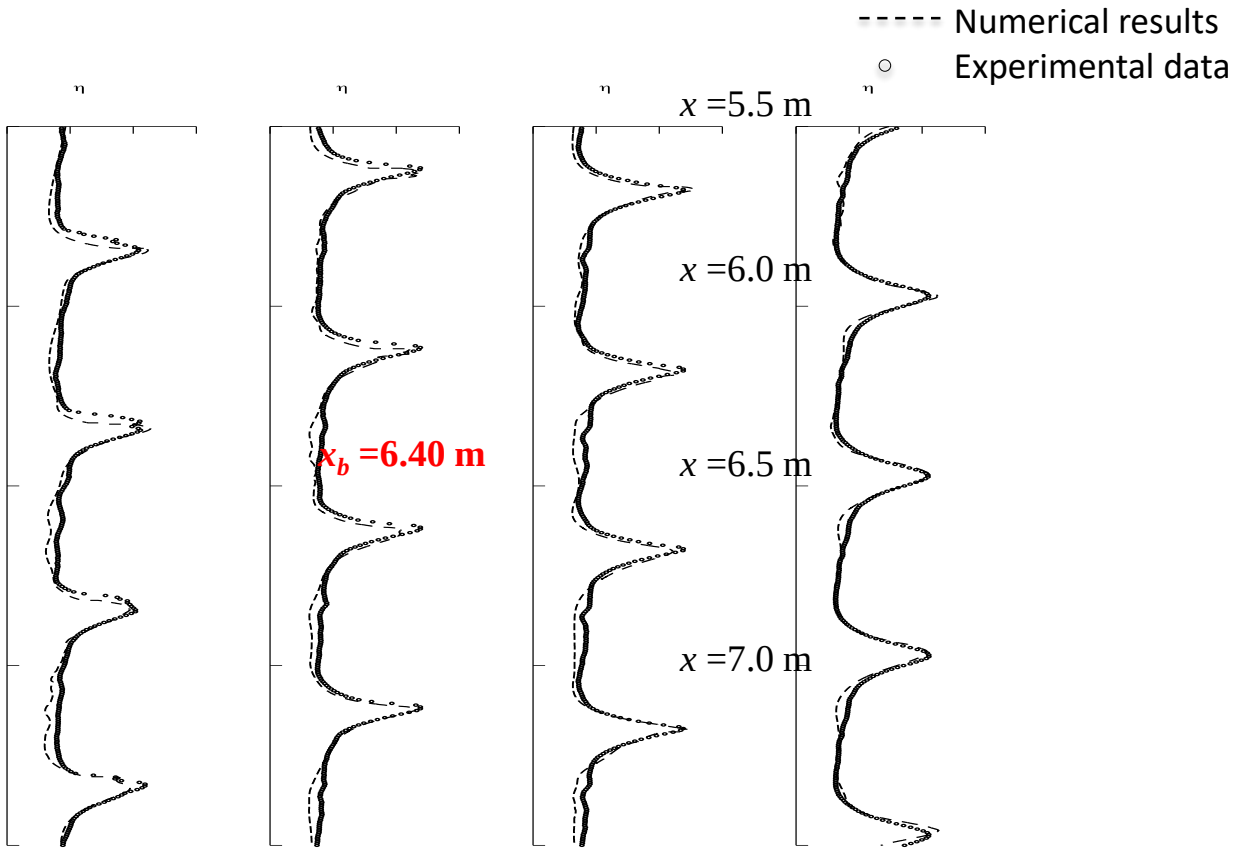
Wave Height H_0= 0.089m
Wave period T= 5.0s

Spilling breaker

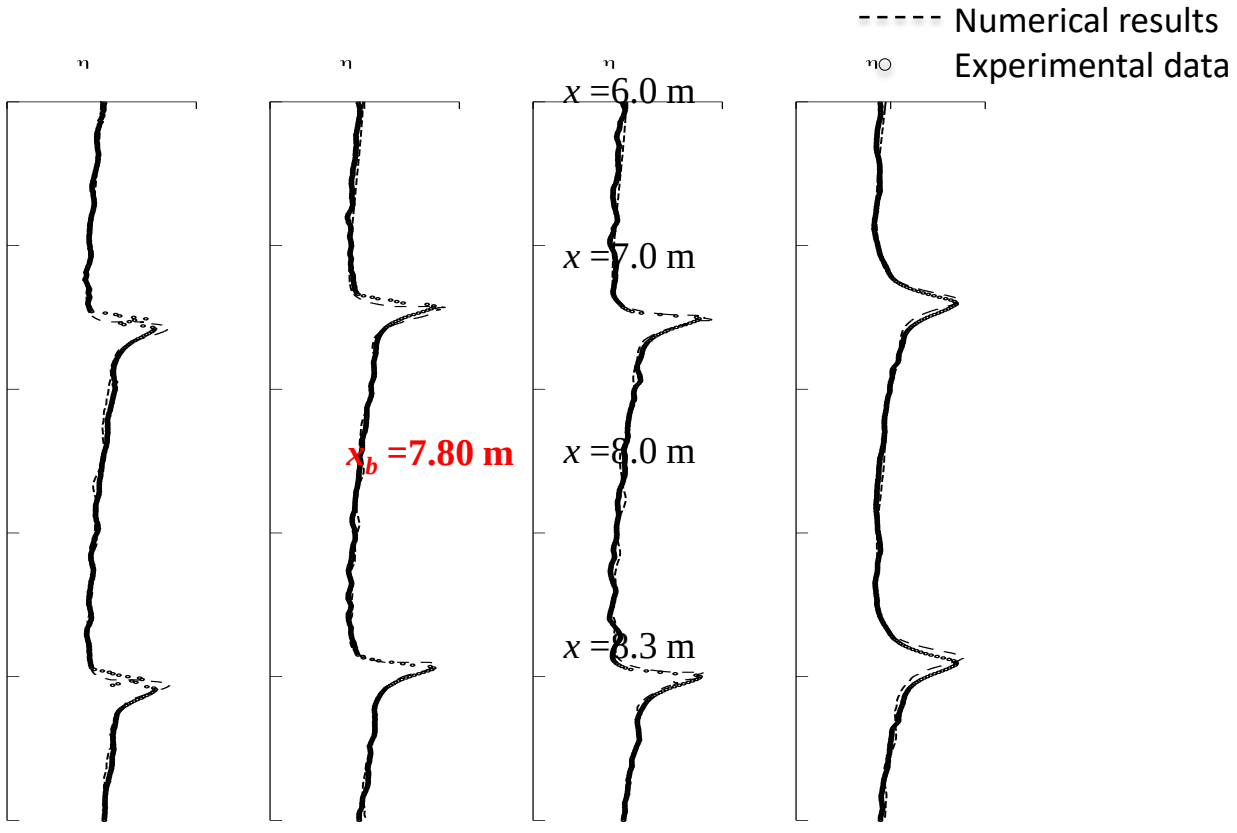
Plunging breaker



Wave surface elevation: Spilling breaker



Wave surface elevation: Plunging breaker

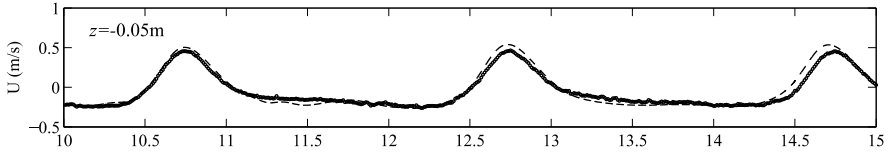


Horizontal velocity component: Spilling breaker

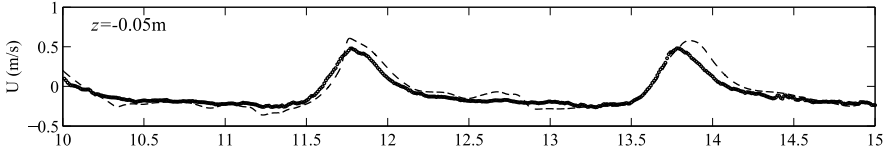
Z=-0.05m

----- Numerical results

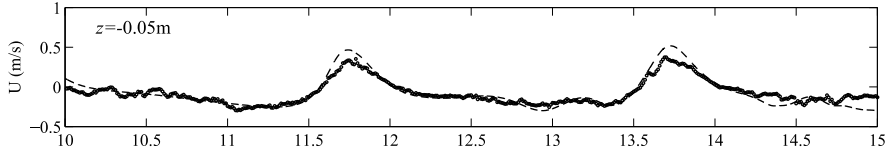
○ Experimental data



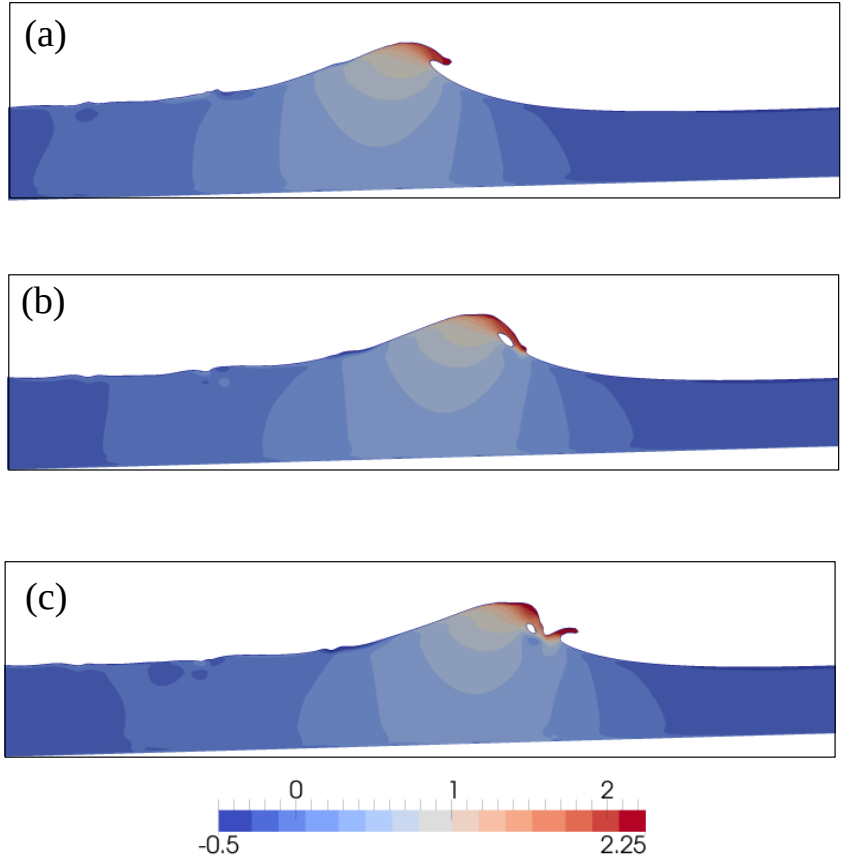
(a) *x*=5.945m (before breaking)



(b) *x*=6.665m (during breaking)



(c) *x*=7.275m (after breaking)

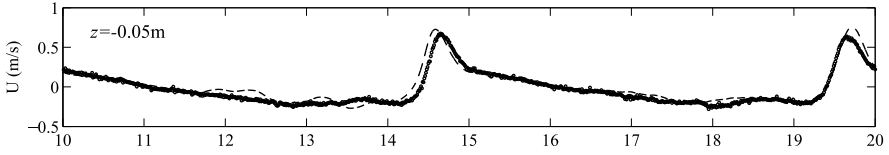


Horizontal velocity component: Plunging breaker

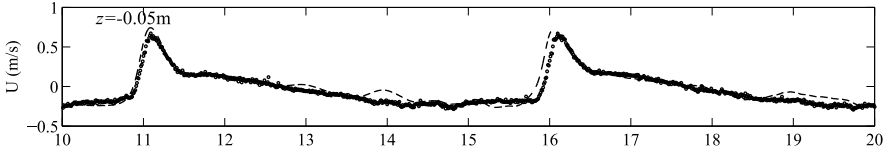
Z=-0.05m

----- Numerical results

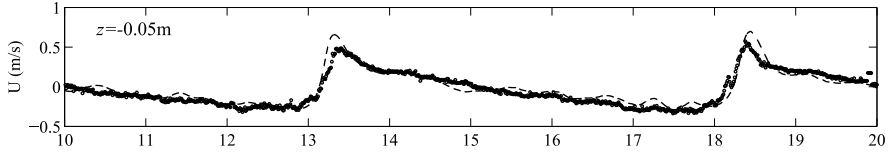
○ Experimental data



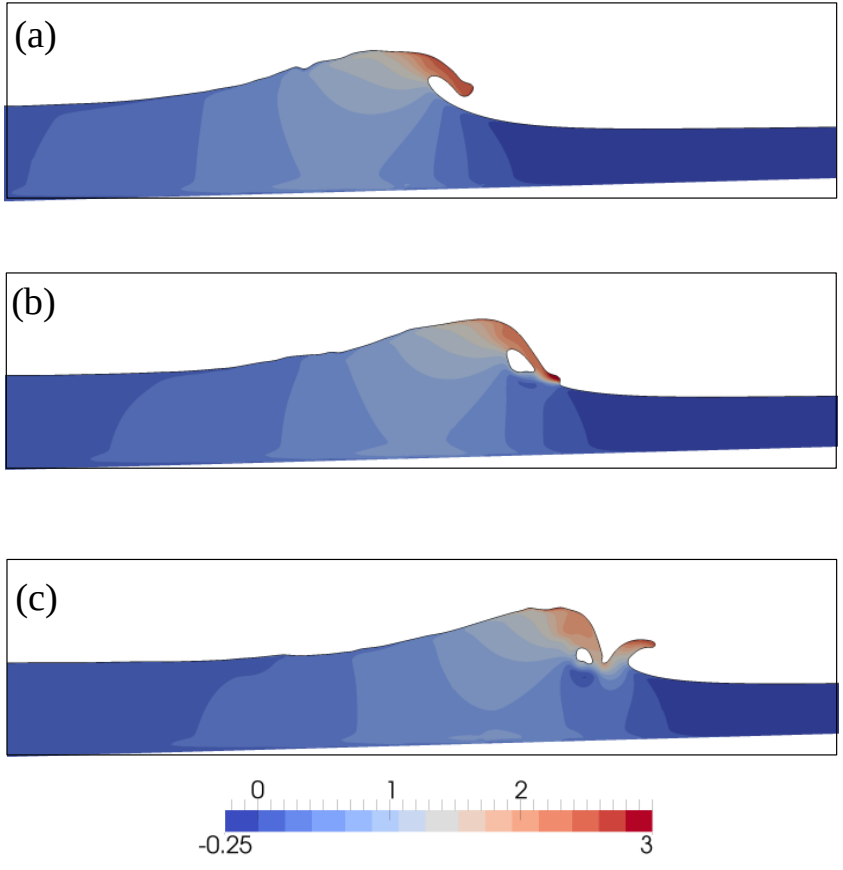
(a) x=7.295m (before breaking)



(a) x=7.725m (during breaking)



(a) x=8.345m (after breaking)

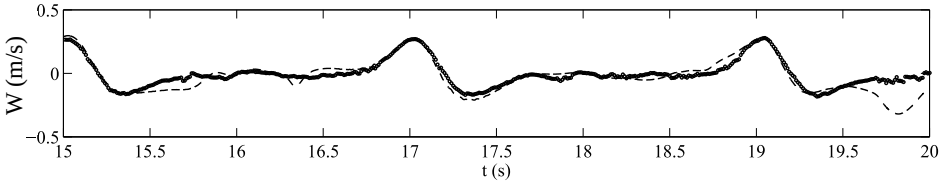


Vertical velocity component: Spilling breaker

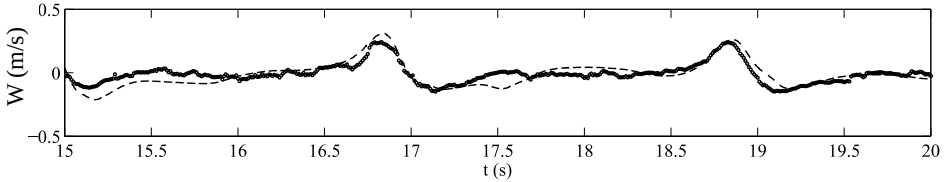
Z=-0.05m

----- Numerical results

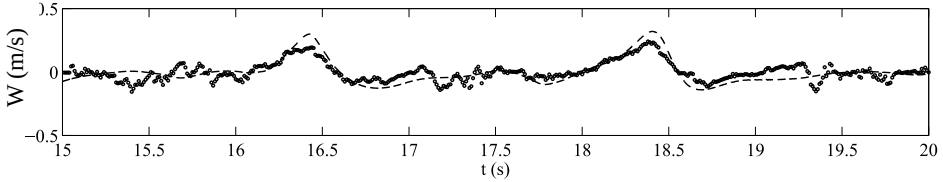
○ Experimental data



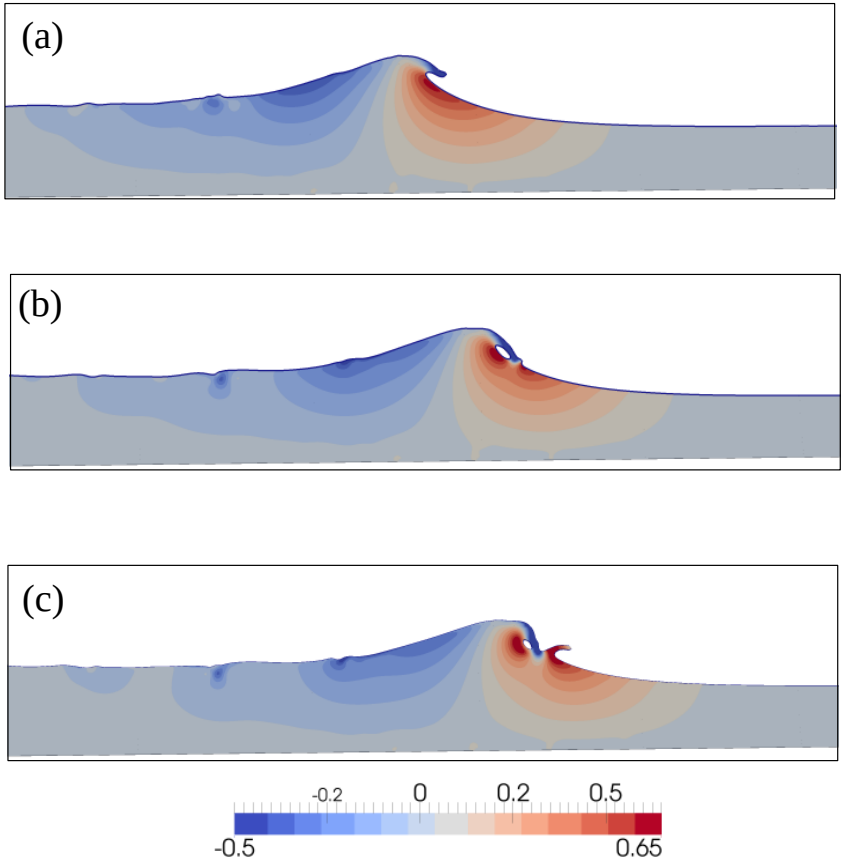
(a) x=5.945m (before breaking)



(b) x=6.665m (during breaking)



(c) x=7.275m (after breaking)

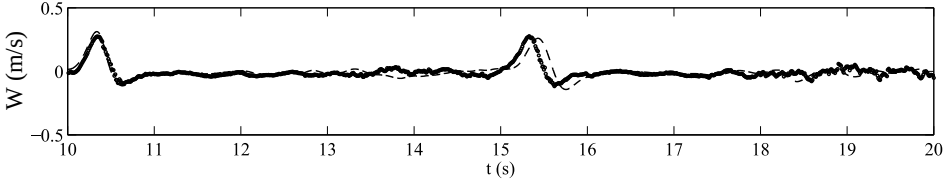


Vertical velocity component: Plunging breaker

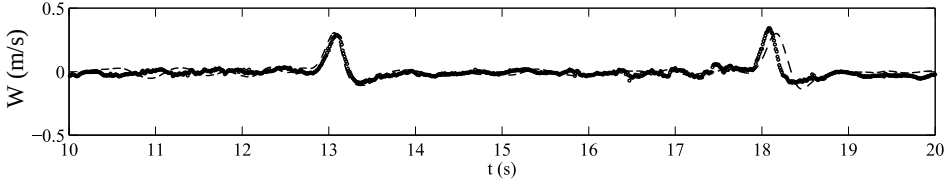
Z=-0.05m

----- Numerical results

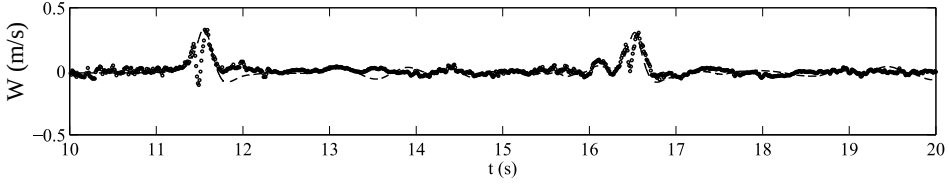
○ Experimental data



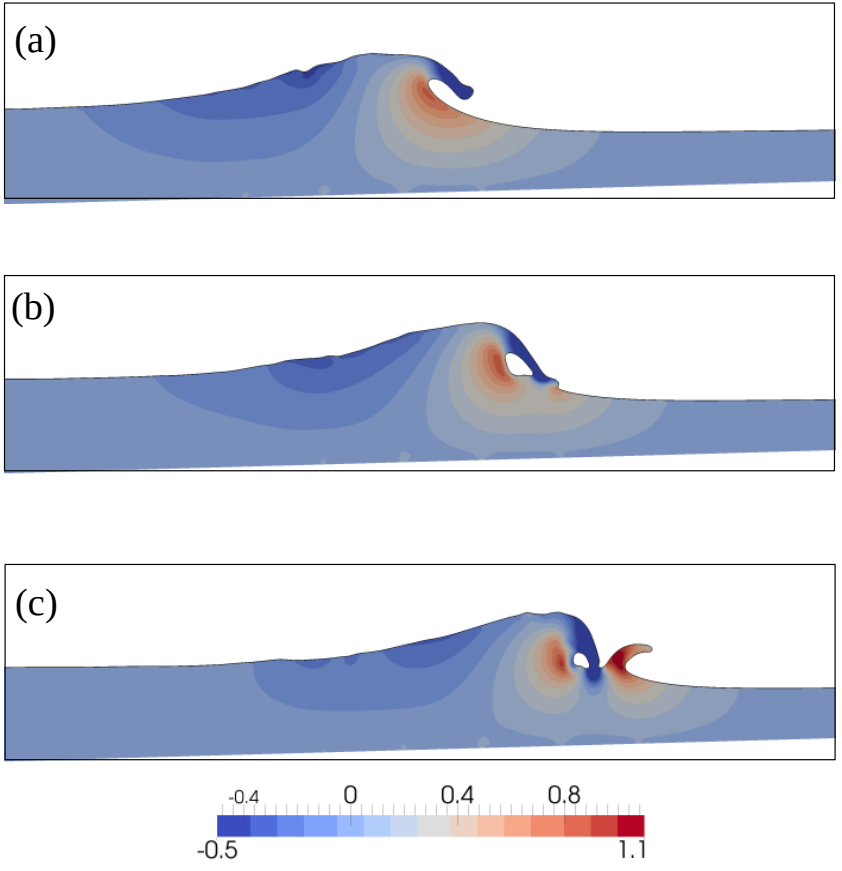
(a) x=7.295m (before breaking)



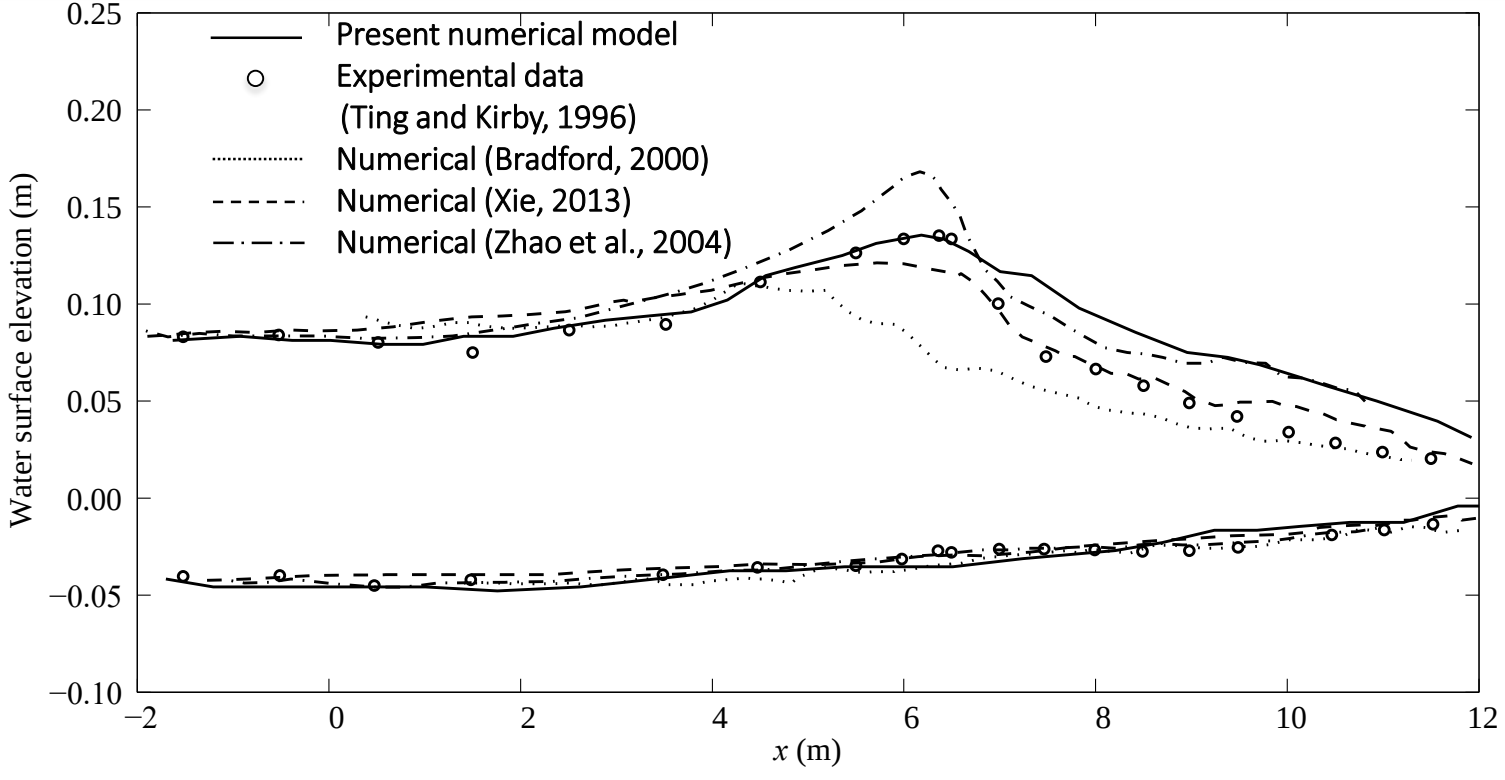
(a) x=7.725m (during breaking)



(a) x=8.345m (after breaking)

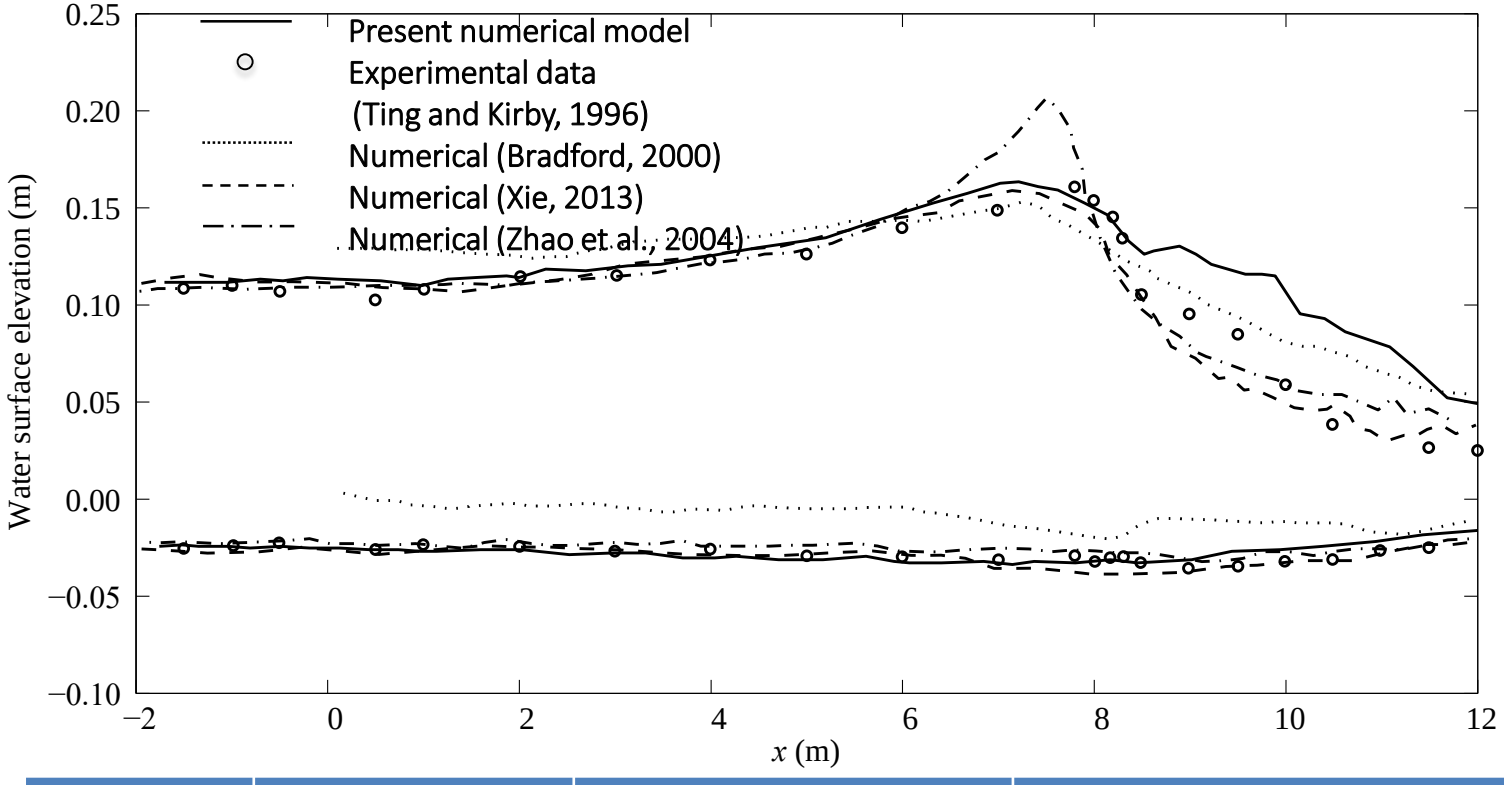


Wave envelope: Spilling breaker



Deep water wave height H_0 (m)	Wave period, T (s)	Experimental results			Numerical results		
		x_b (m)	H_b(m)	H/d	x_b(m)	H_b(m)	H/d
0.127	2.0	**6.40**	**0.165**	**0.78**	**6.28**	**0.172**	**0.775**

Wave envelope: Plunging breaker



Deep water wave height H_0 (m)	Wave period, T (s)	Experimental results			Numerical results		
		x_b (m)	H_b(m)	H/d	x_b(m)	H_b(m)	H/d
0.127	2.0	**7.795**	**0.191**	**1.24**	**7.84**	**0.205**	**1.164**

Geometric properties

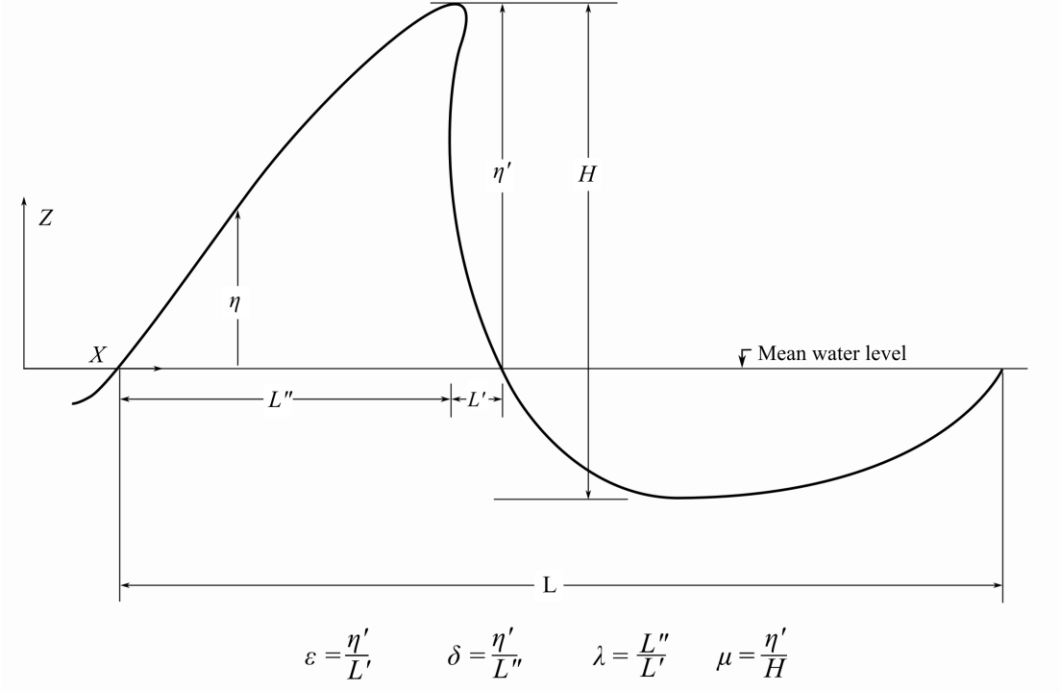
Kjeldsen and Myrhaug (1978)

Crest front steepness $\varepsilon = \frac{\eta'}{L'}$

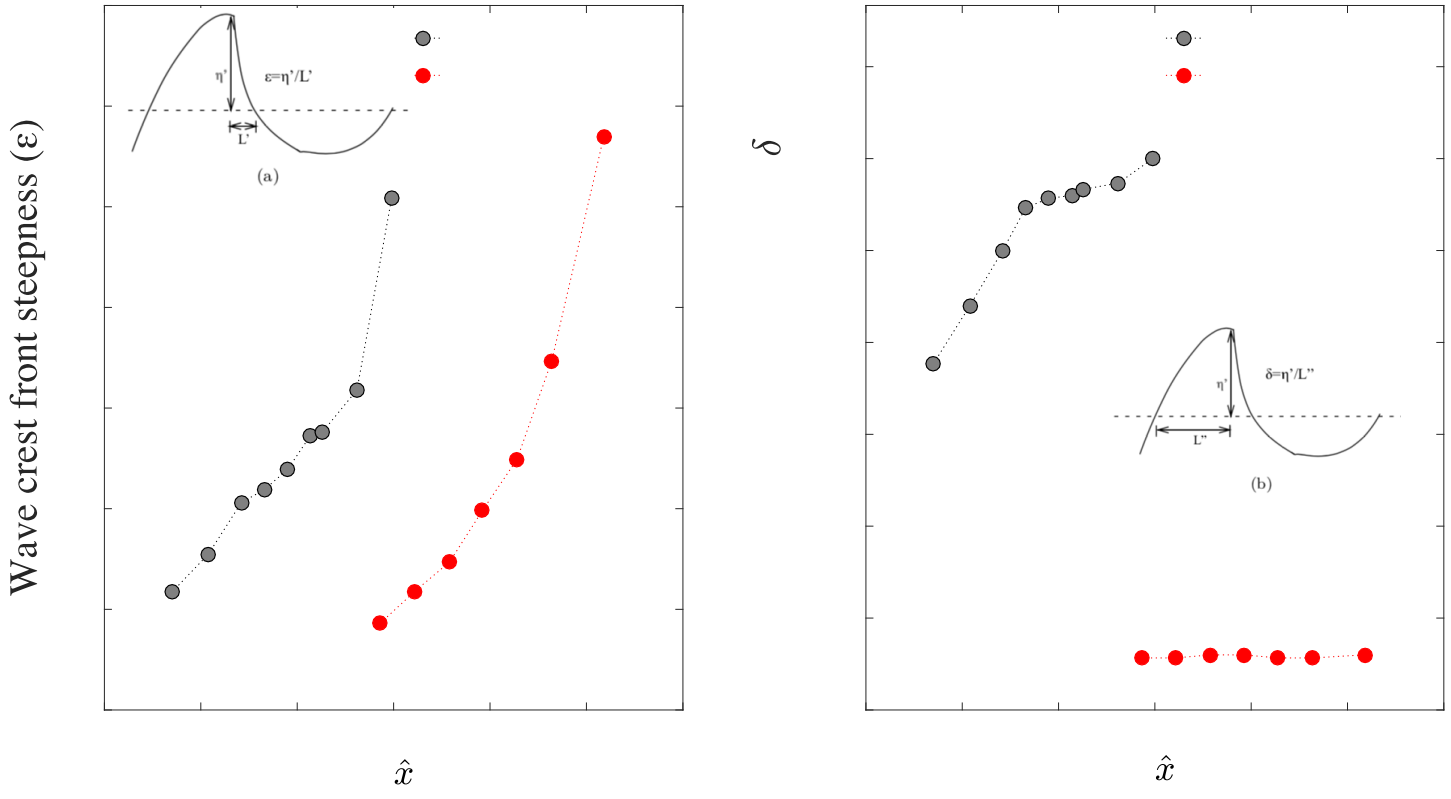
Crest rear steepness $\delta = \frac{\eta'}{L''}$

Horizontal asymmetry factor $\mu = \frac{\eta'}{H}$

Vertical asymmetry factor $\lambda = \frac{L''}{L'}$

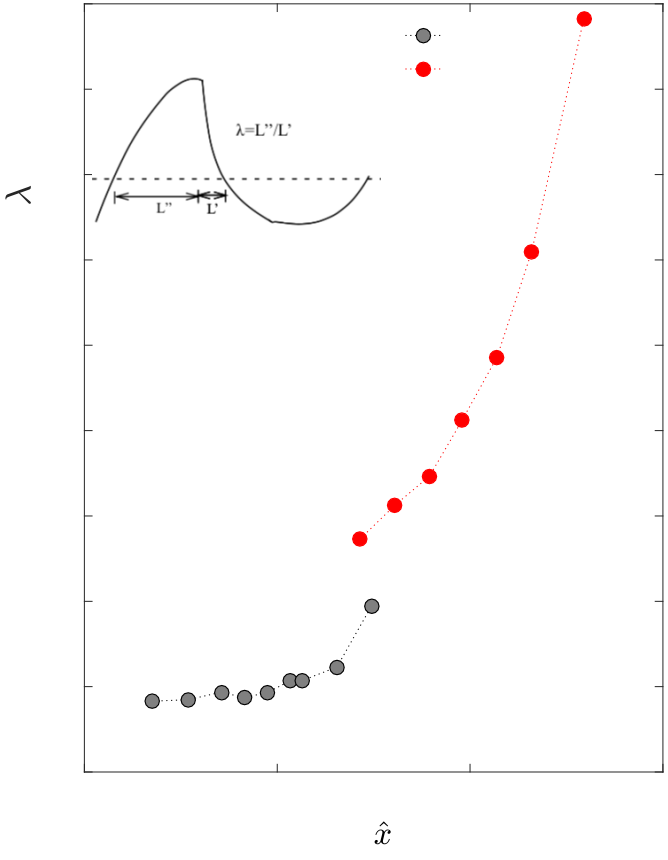


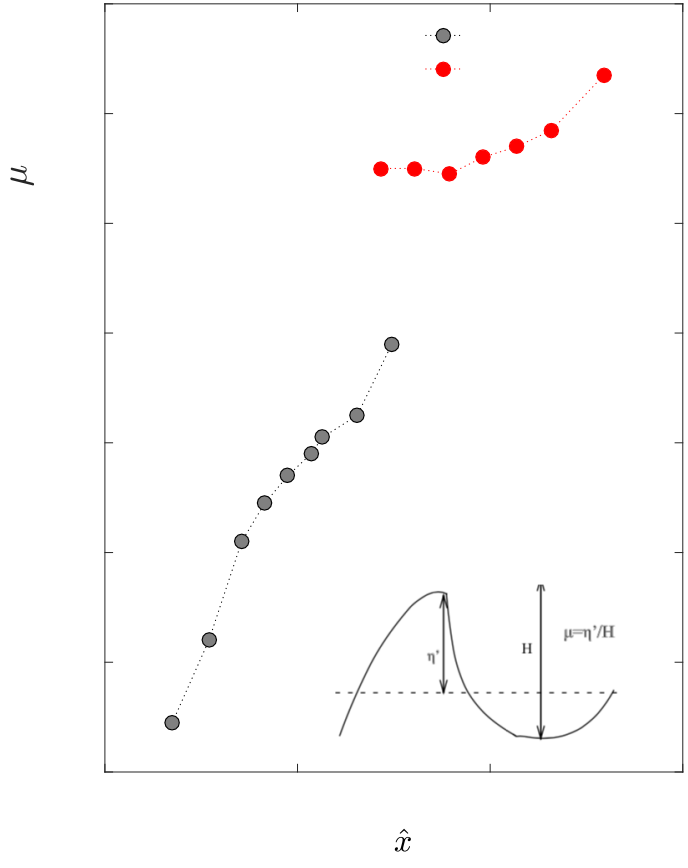
Geometric properties



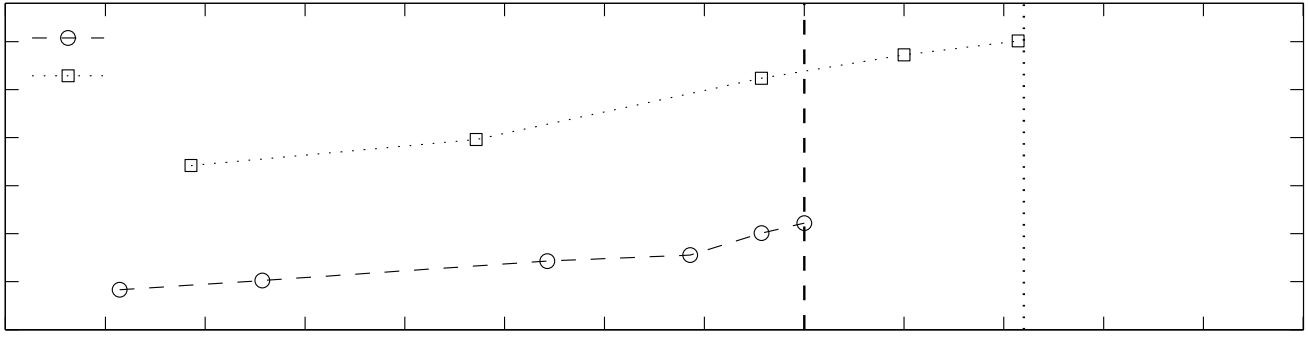
$\hat{x}$ - Normalized distance up to the breaking point

Geometric properties

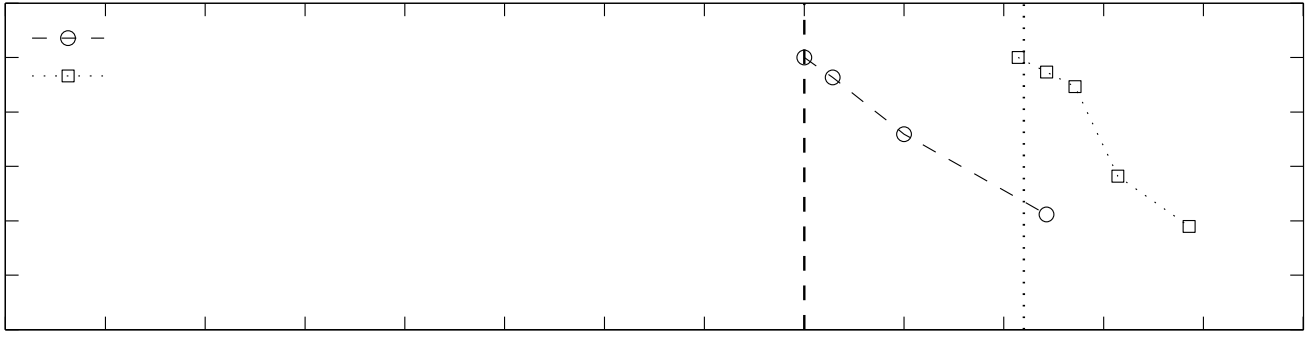




Wave characteristics during breaking

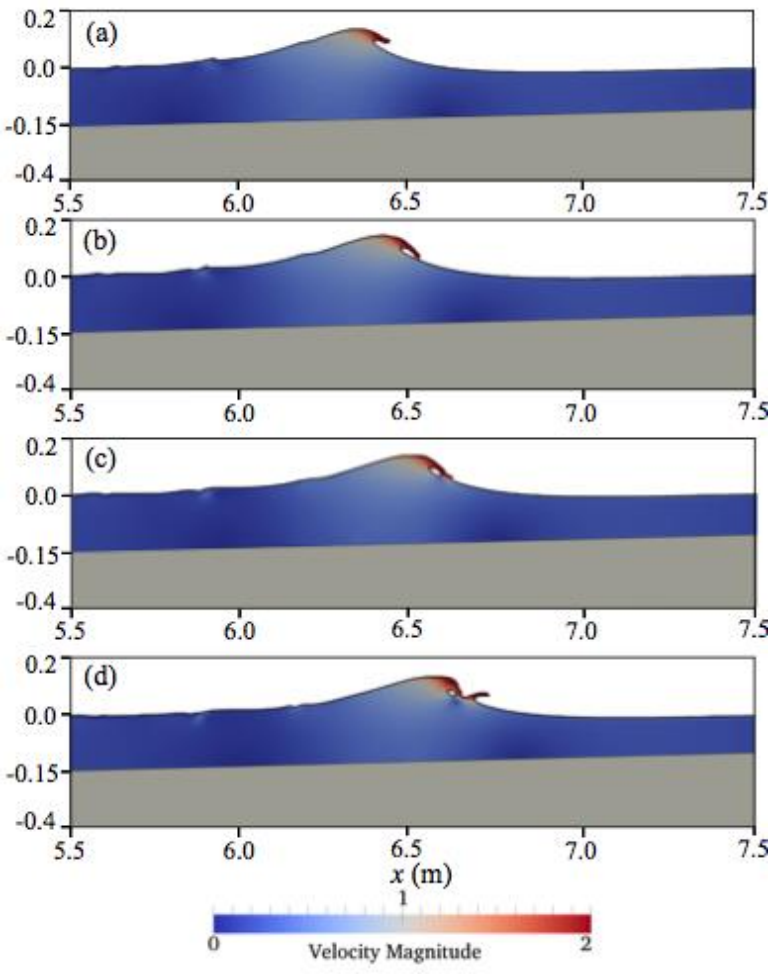


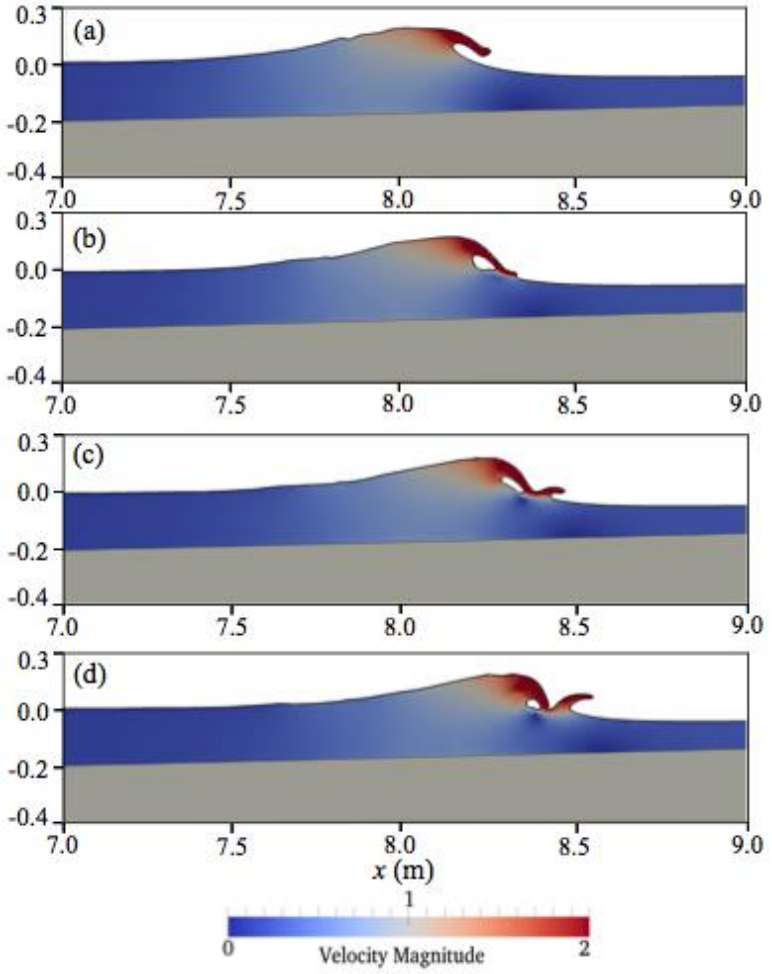
$\hat{x}$



$\hat{x}$

Spilling breakers versus plunging breakers





Summary

- Comparison between experimental and numerical results shows good agreement for both spilling and plunging breaker

- Characteristics and geometric properties:
  - Plunging breaker: Larger breaker height and rapid wave attenuation
  - Degree of asymmetry is high for plunging breakers

- Flow features: Forward overturning water jet, air pocket, splash-up, and the secondary wave during the breaking process

- REEF3D can provide a good representation for the complete wave transformation process from wave generation, shoaling and onset of wave breaking to post-breaking

Acknowledgments

Travel grant:

Thank you for your attention