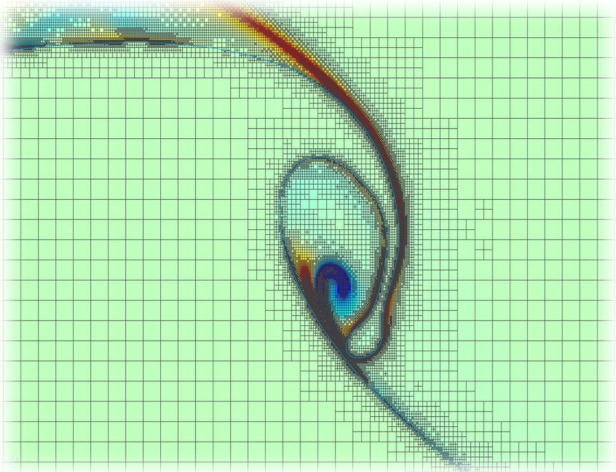
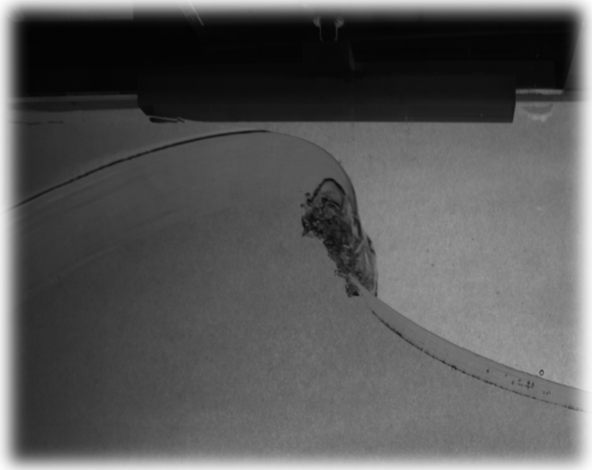
Basilisk (Gerris) Users' Meeting
Paris, France, 5-7 July, 2023

Shallow Water Breaking Waves On a Flat Bottom

LIU Shuo, WANG Hui, COUTIER-DELGOSHA Olivier, BAYEUL-LAINE Annie-Claude



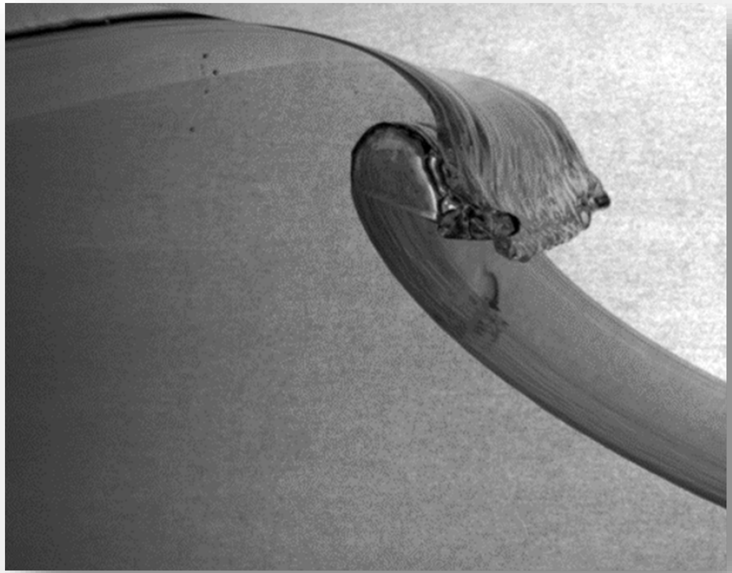


Arts et Métiers Sciences et Technologies

Virginia Tech | Advanced Research Computing

Laboratoire de Mécanique des Fluides de Lille Kampé de Fériet

Motivation



Experimental wave replication

Wave dynamics

Cavity dependence

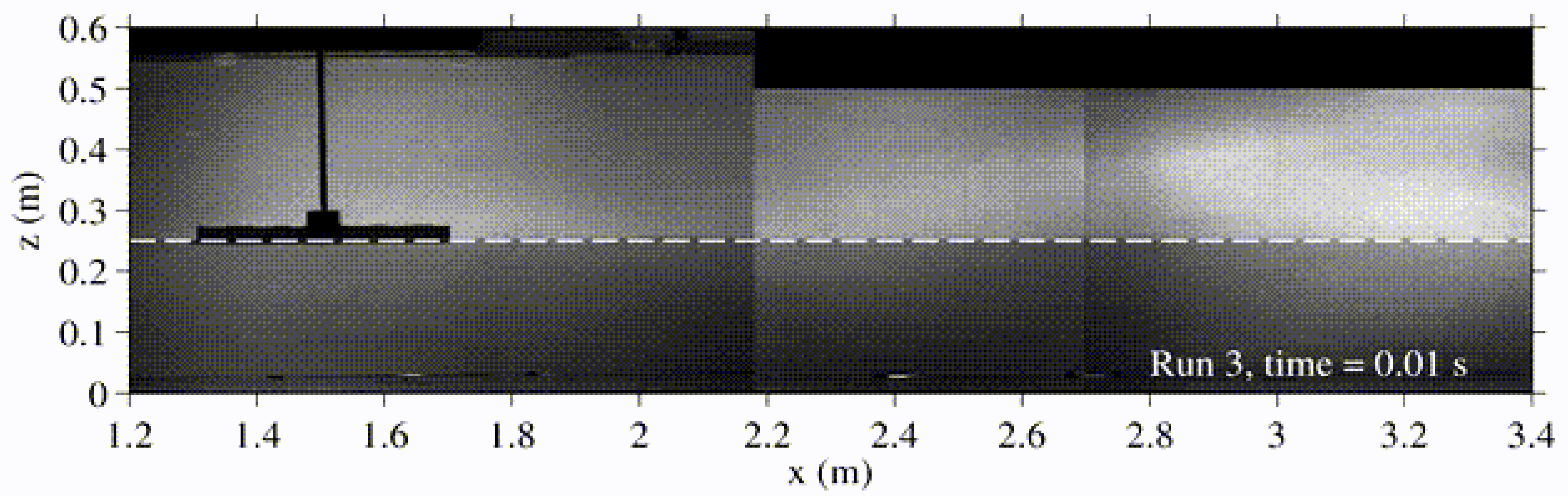
Breaking dissipation

Shallow water

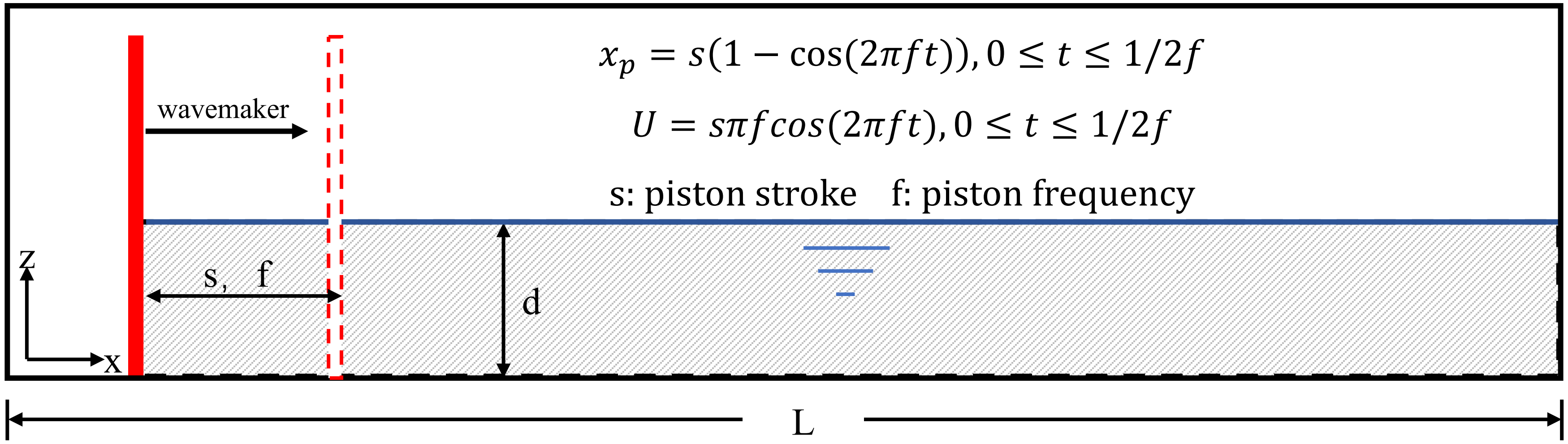
Wave breaking

Level bottom

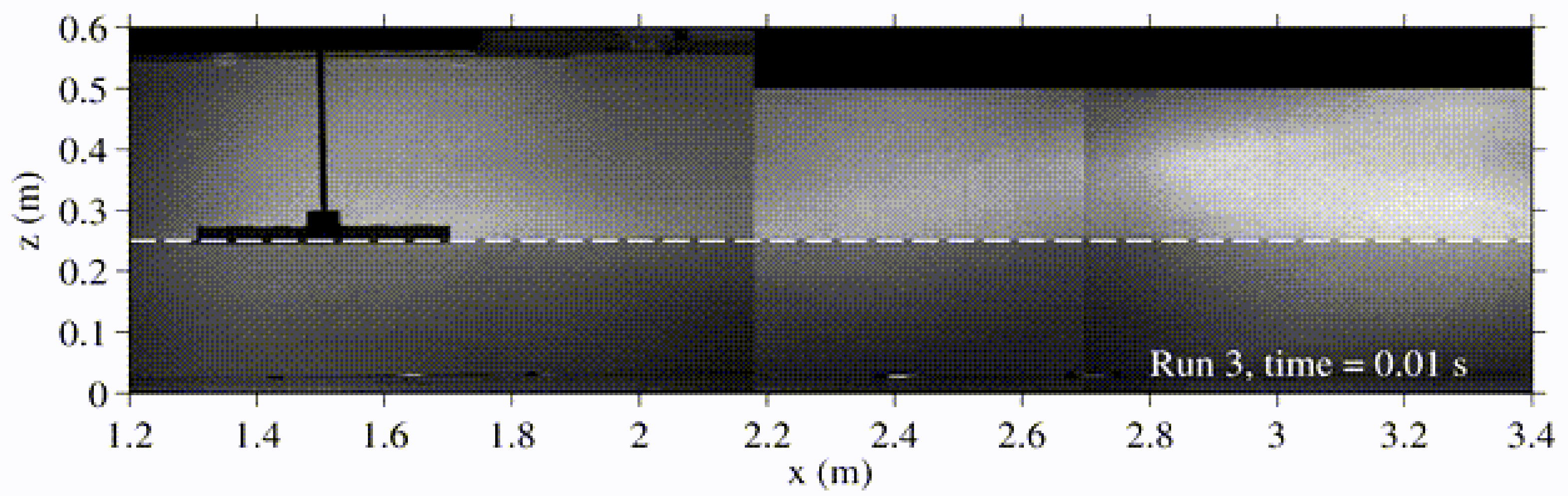
Lab experiments



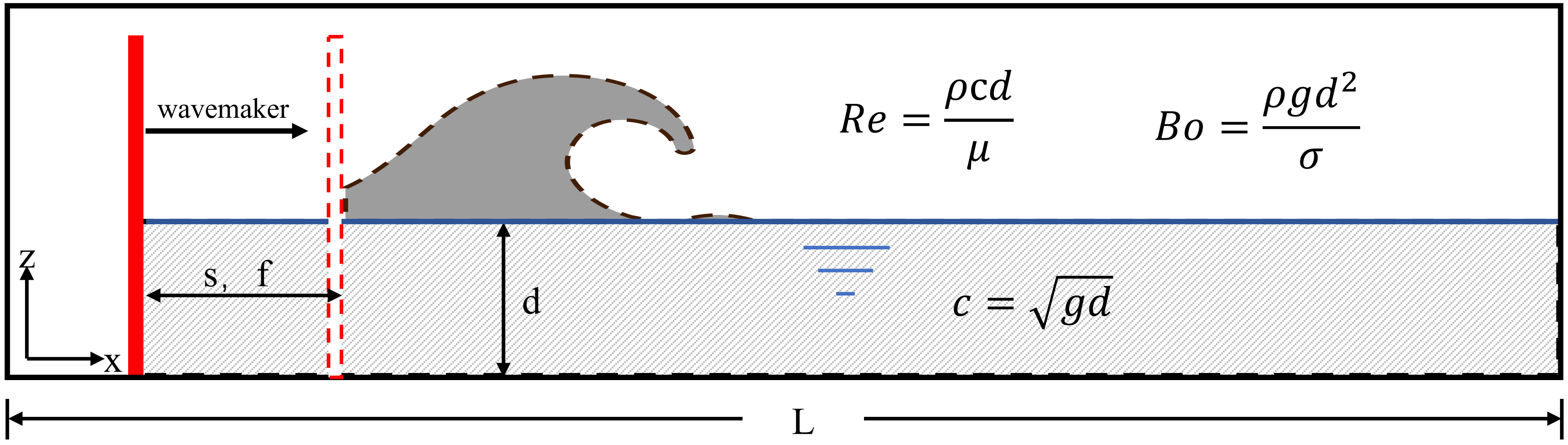
Wei et al., Chaos in breaking waves, *Coastal Engineering*, 2018.
Video credit: Cheng Li & Joseph Katz, JHU



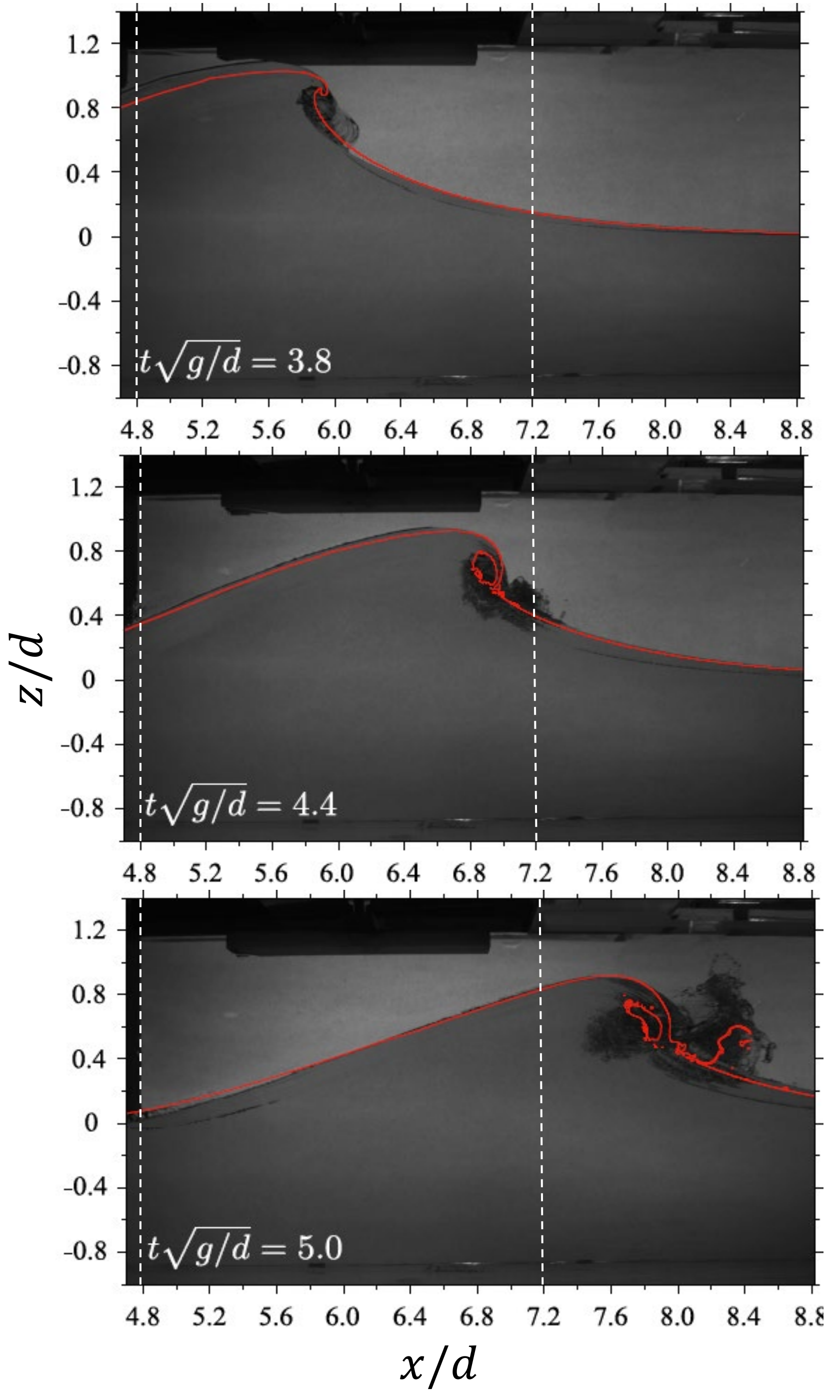
Lab experiments



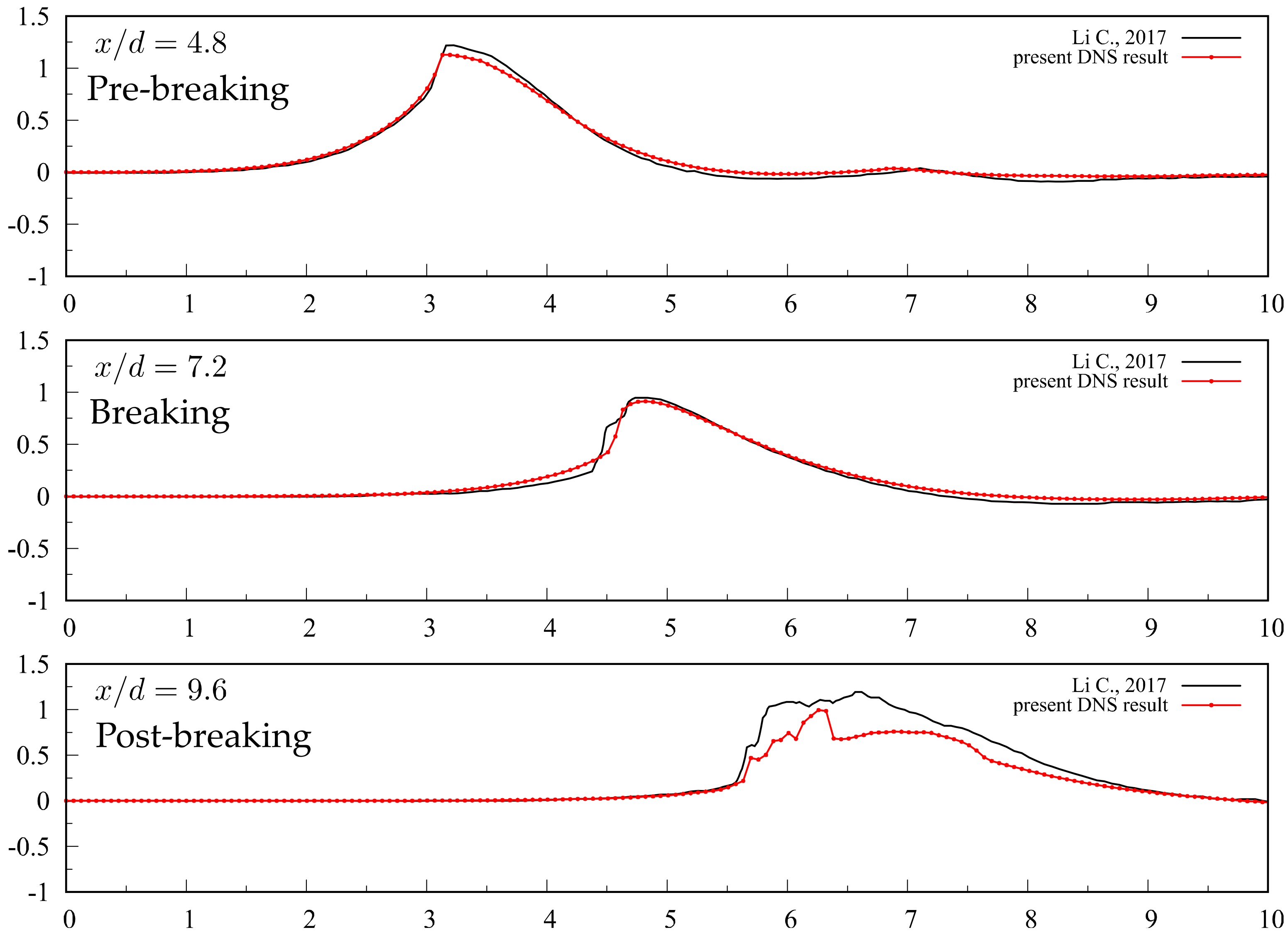
Wei et al., Chaos in breaking waves, *Coastal Engineering*, 2018.
Video credit: Cheng Li & Joseph Katz, JHU

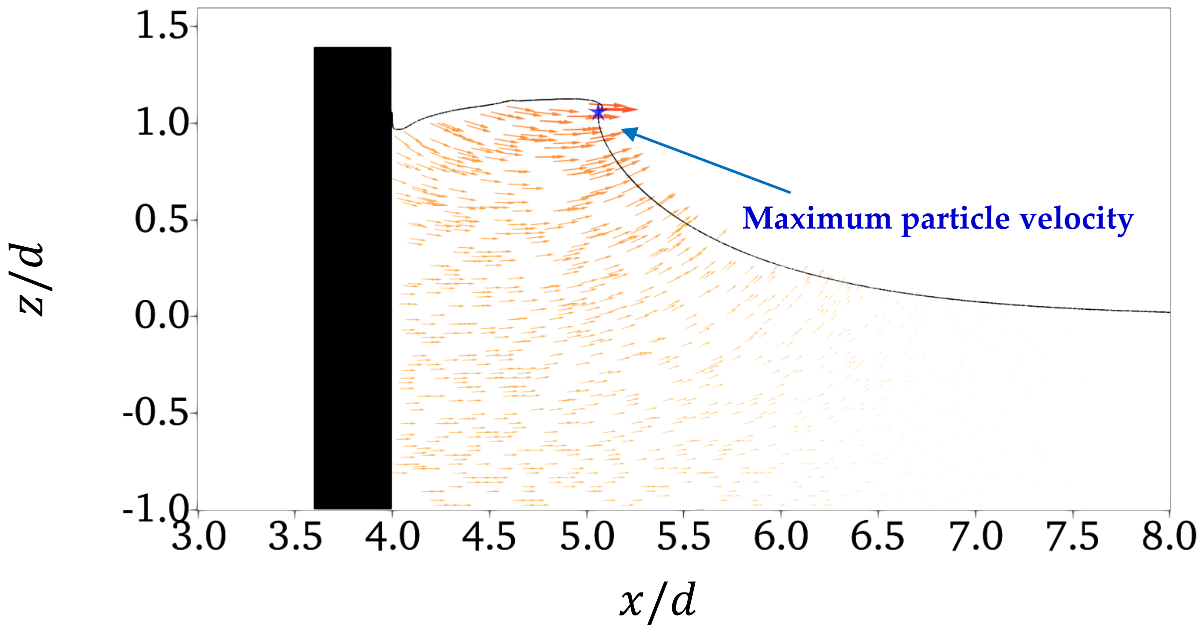


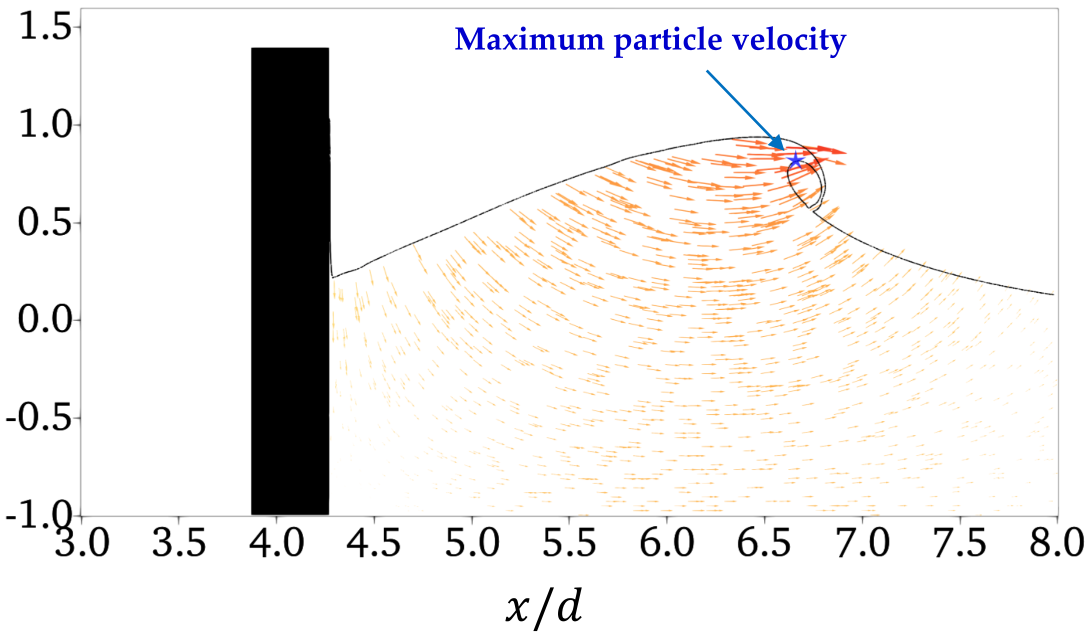
Model verification



Comparison of free surface profile




1.5
1.0
0.5
0.0
-0.5
-1.0
z/d
3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0
x/d
Maximum particle velocity

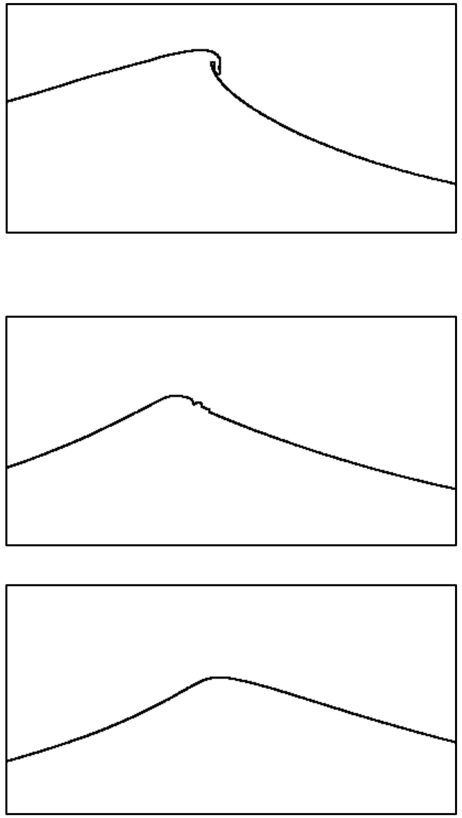

1.5
1.0
0.5
0.0
-0.5
-1.0
3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0
x/d
Maximum particle velocity

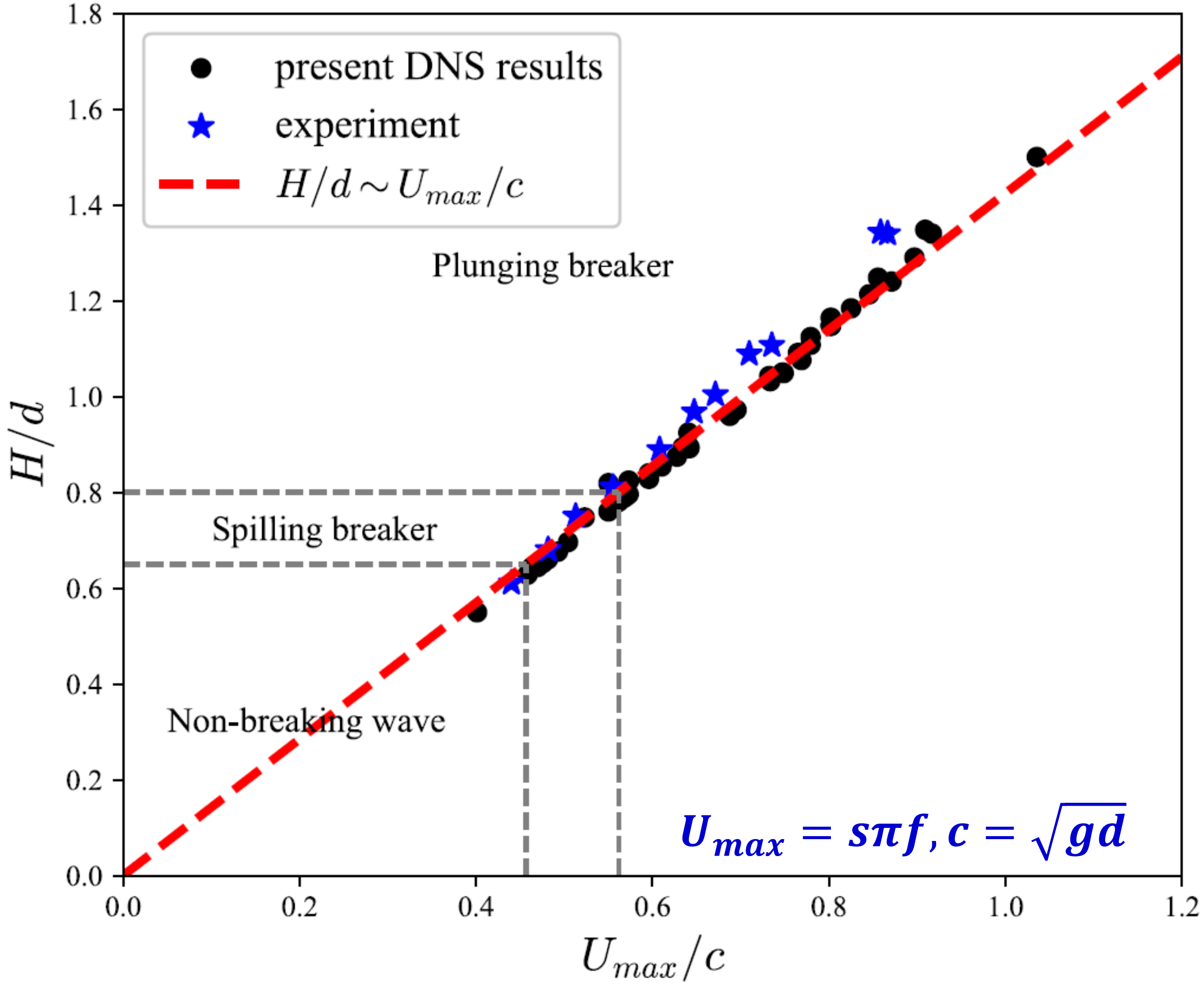
Breaking criterion

Relationship between wave height and maximum wave plate speed

The wave characteristics are controlled by varying the initial condition of the wave plate (s, f, d).

Identifying wave types using H/d



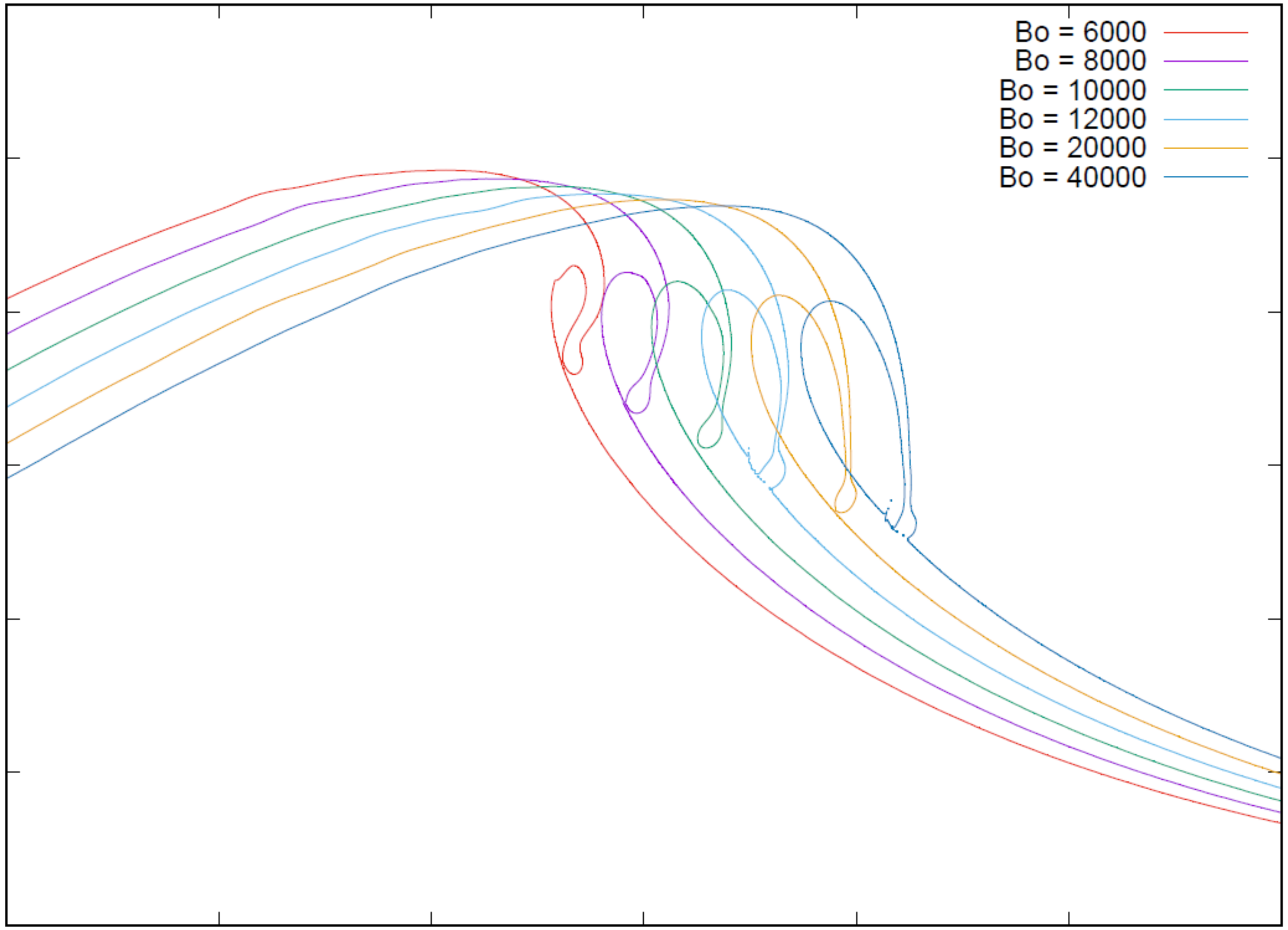


Relationship between H/d and U_{max}/c

Main cavity dependency

Relationship between surface tension and main cavity size

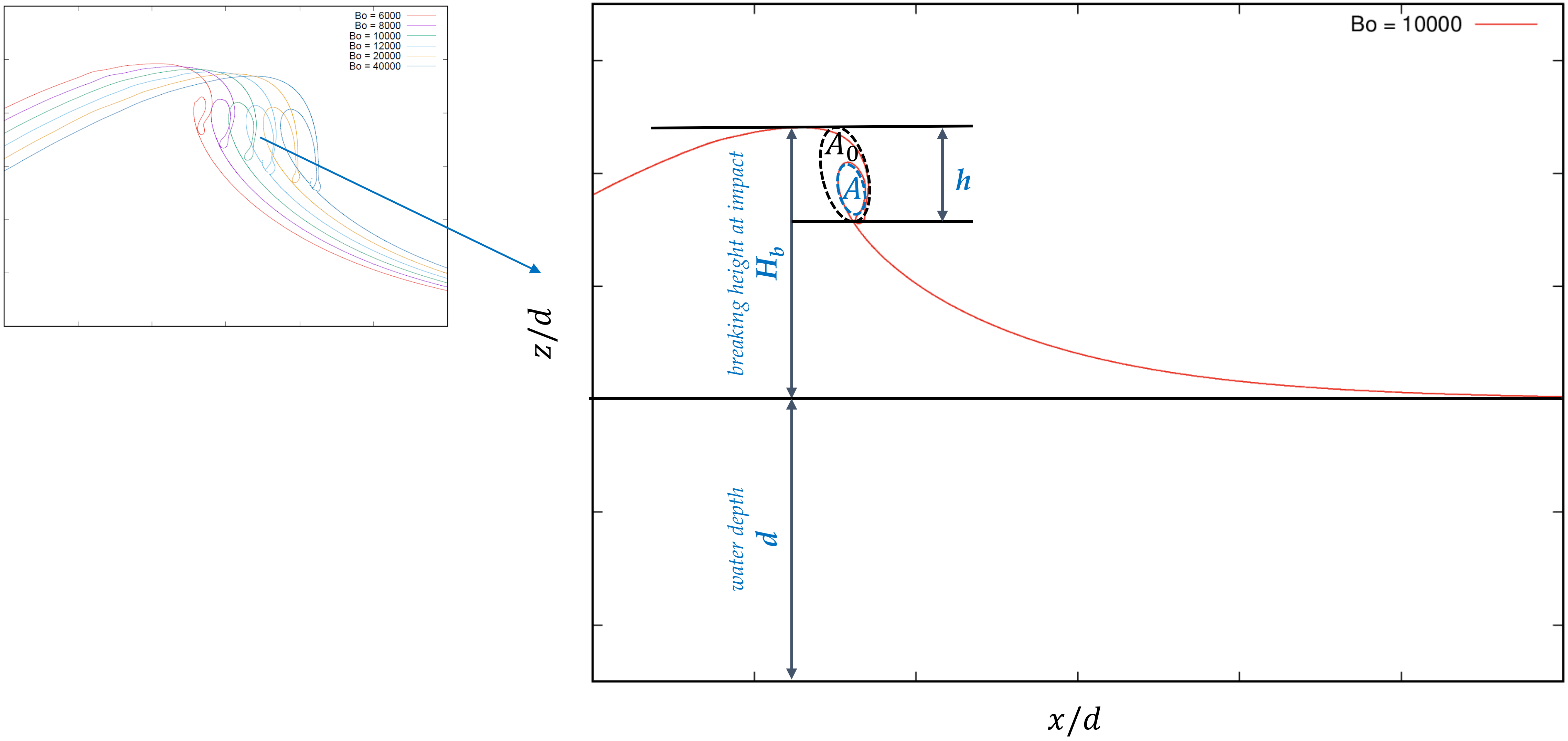
The main cavity size are controlled by varying the Bond number ($Bo = \rho g d^2/\sigma$).

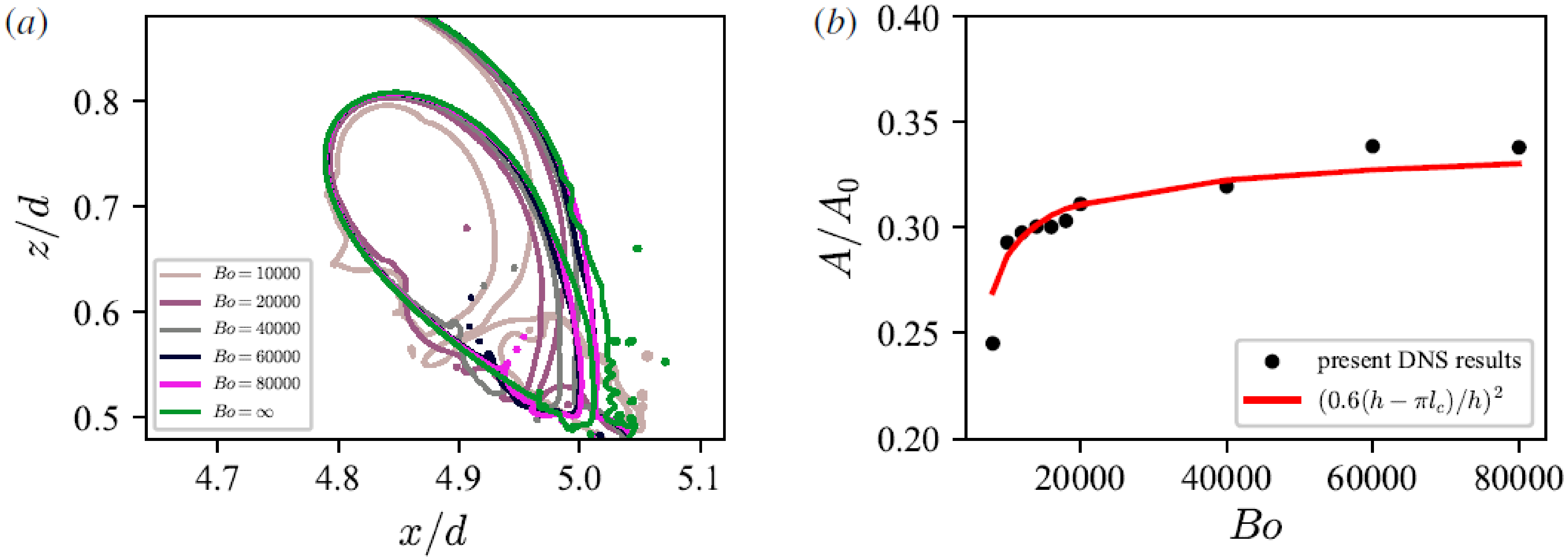


Main cavity dependency

Relationship between surface tension and main cavity size

The main cavity size are controlled by varying the Bond number ($Bo = \rho g d^2/\sigma$).

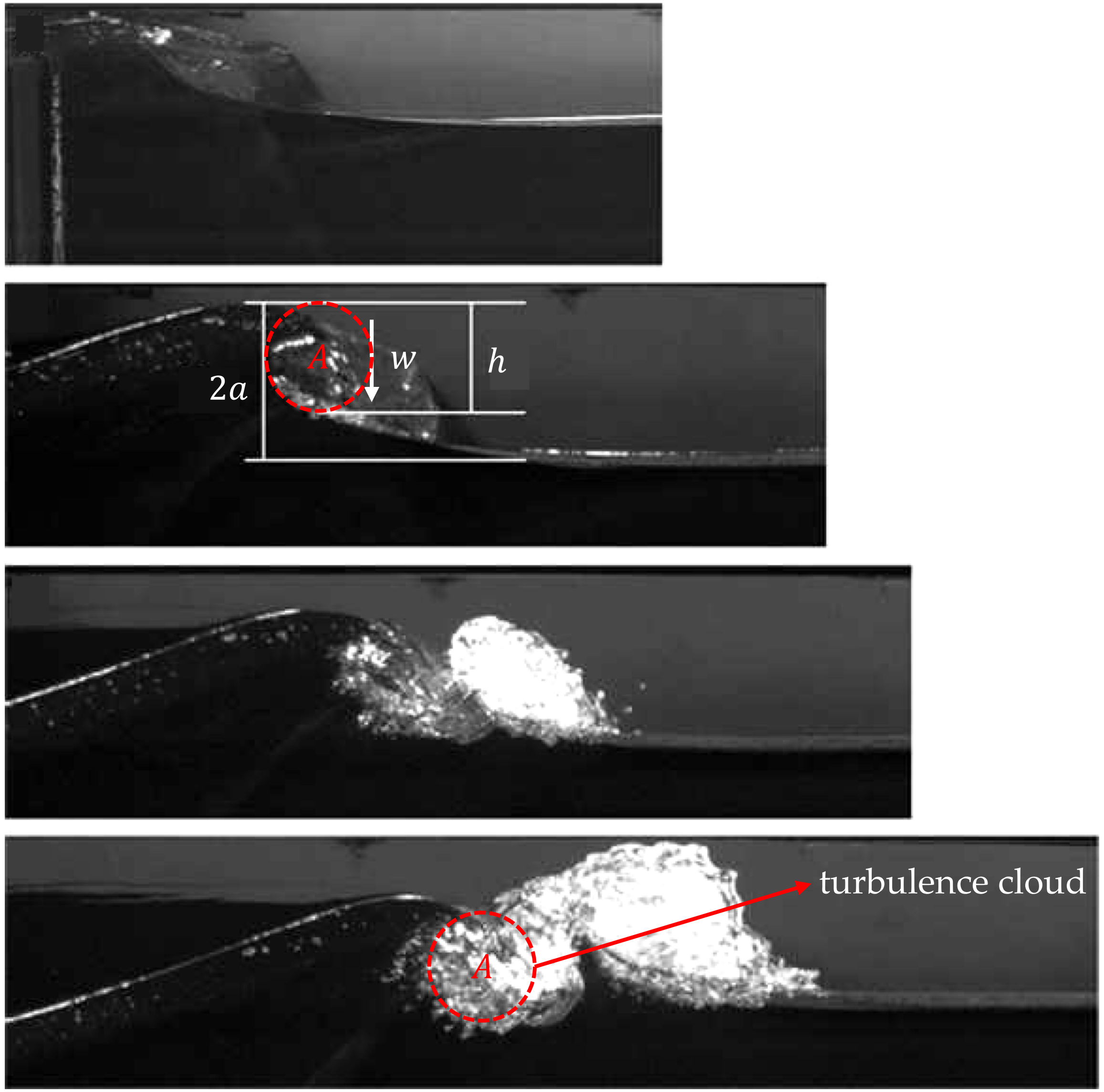




$$capillary\ length:\ l_c = \sqrt{\frac{\sigma}{\Delta\rho g}} = \frac{d}{\sqrt{Bo}}$$

Energy dissipation by breaking waves (deep water)

Inertial scaling of dissipation due to breaking:



Free fall assumption:

$$w = \sqrt{2gh}$$

Inertial estimate for the dissipation per unit mass:

$$\epsilon = \chi\left(\frac{w^3}{h}\right) = \chi(2g)^{3/2}\ h^{1/2}$$

Dissipation per unit length of wave crest:

$$\epsilon_l = \rho A \epsilon = \chi \frac{\pi}{\sqrt{2}} \rho g^{3/2}\ h^{5/2}$$

where $A \approx \pi h^2/4$ by assuming a cylindrical turbulence cloud

Breaking parameter:

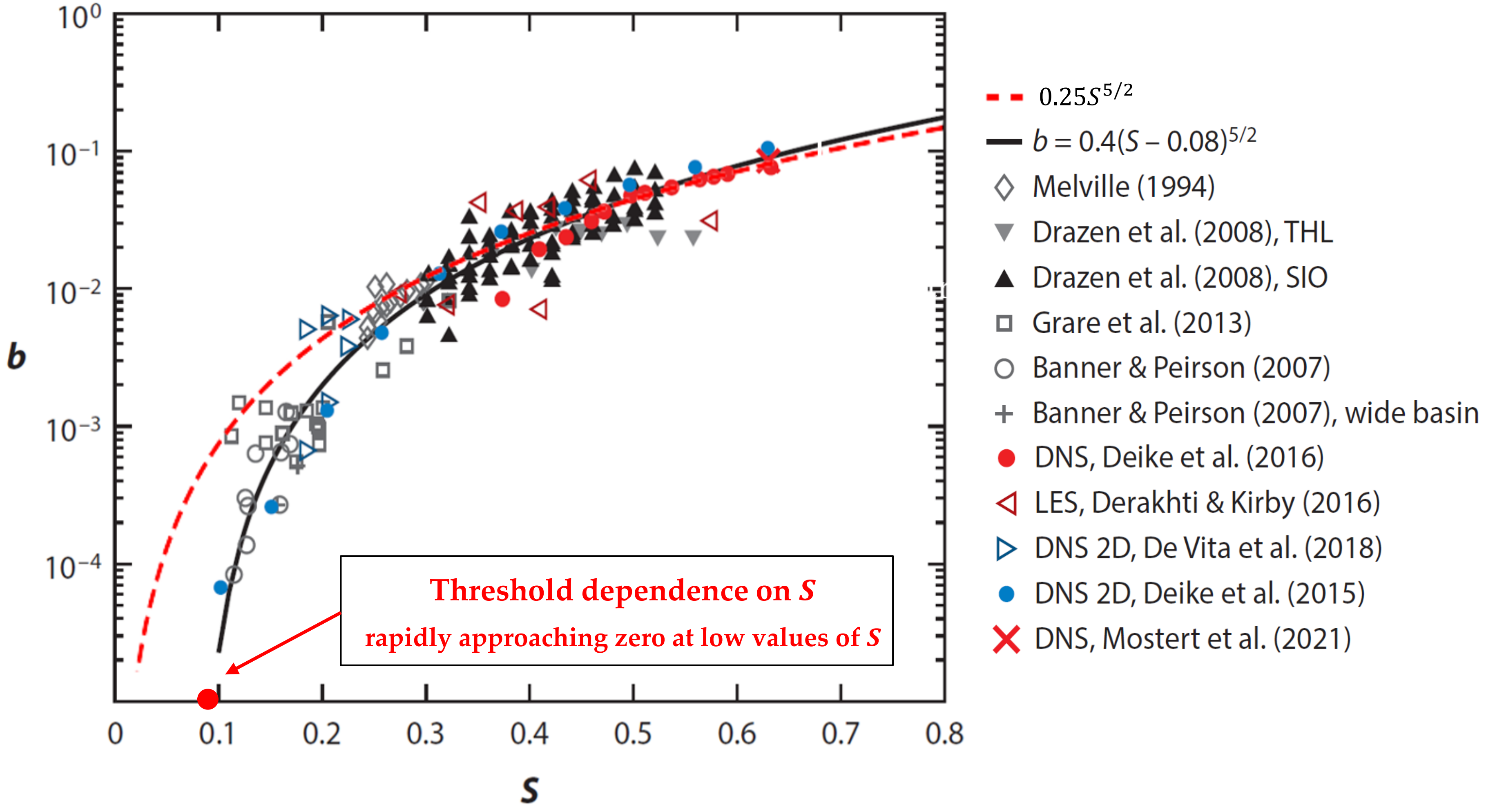
$$b = \frac{\epsilon_l g}{\rho c^5} = \beta (hk)^{5/2} \propto S^{5/2}$$

where $k = g/c^2$ by dispersion relation in deep water

$S = hk$ is the breaking wave slope

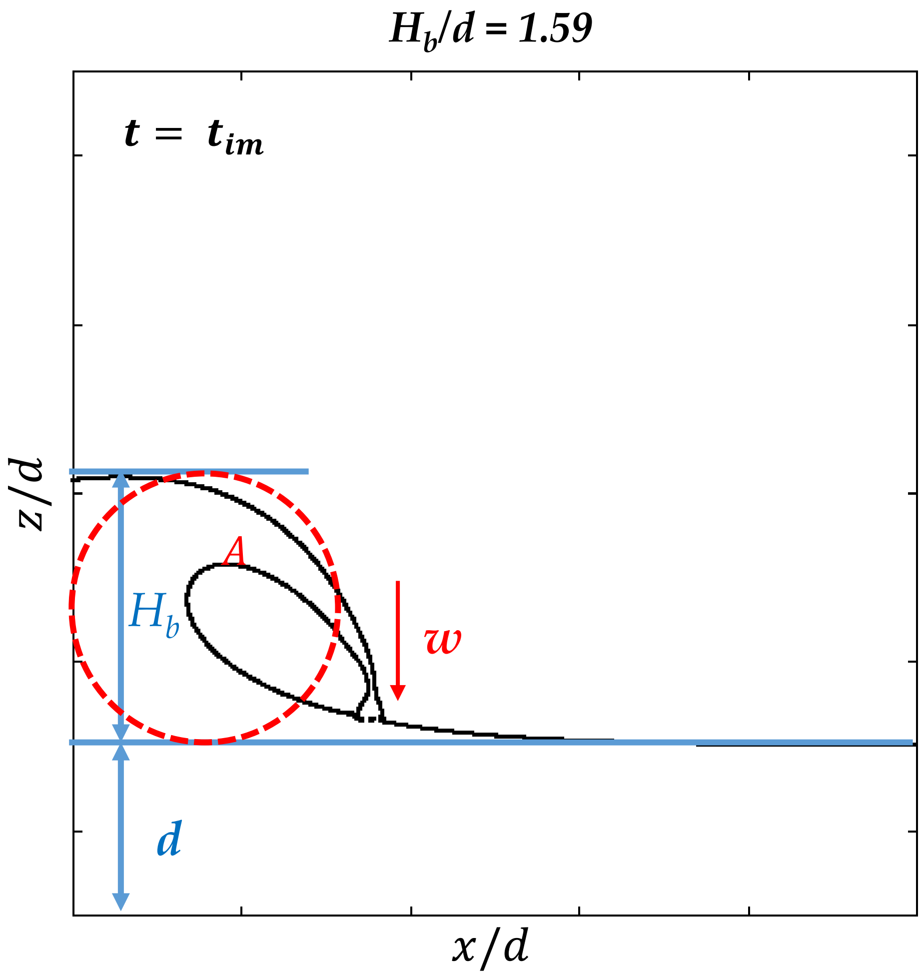
Drazen D A, Melville W K, Lenain L U C. Inertial scaling of dissipation in unsteady breaking waves[J]. Journal of fluid mechanics, 2008, 611: 307-332.

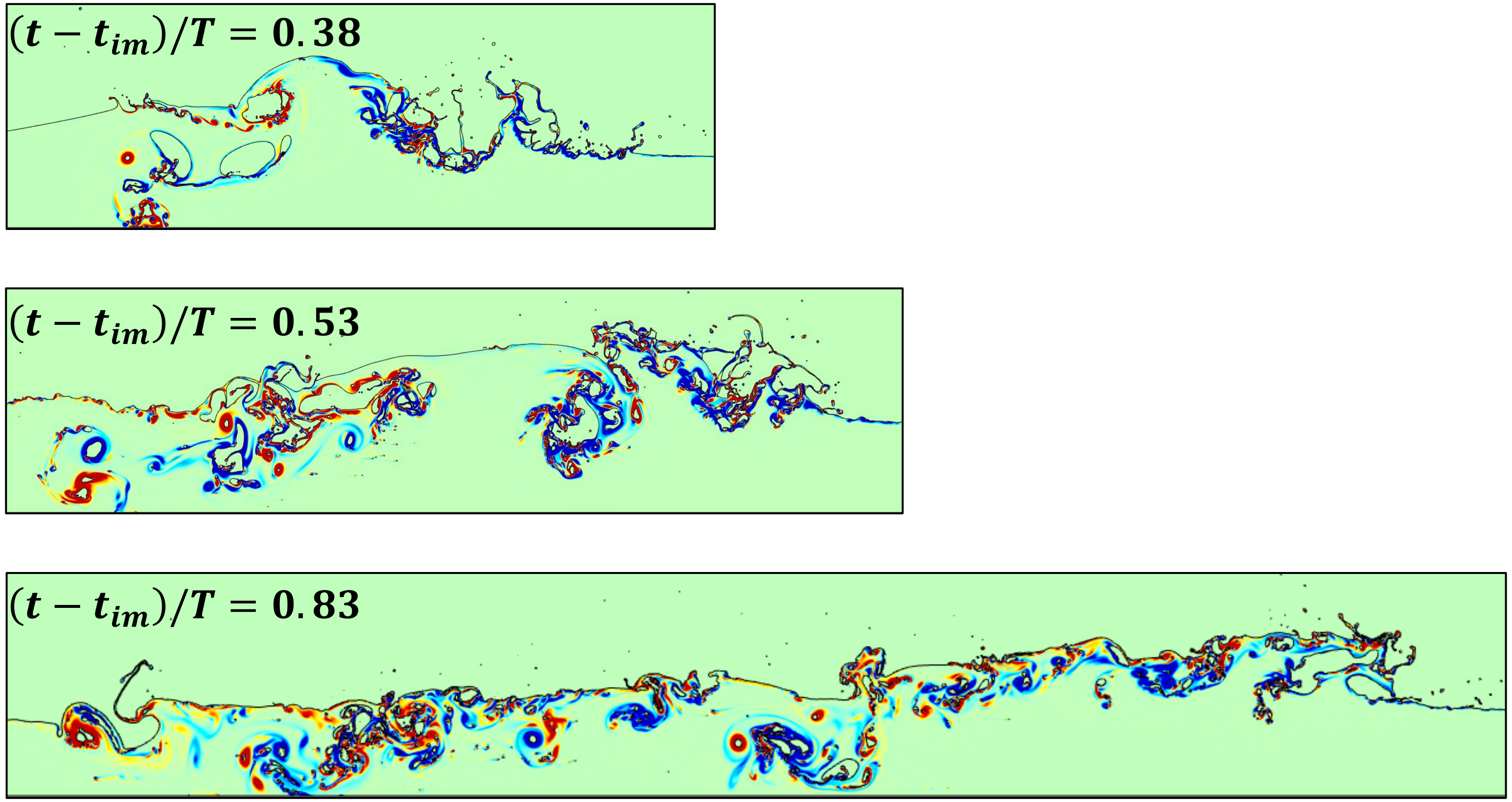
Breaking strength (deep water)



Breaking parameter b as a function of the wave slope: The inertial scaling of b ∝ $S^{5/2}$ derived by Drazen et al. (2008); and the semi-empirical scaling of b ∝ $(S - S_0)^{5/2}$ by Romero et al. (2012). Data from laboratory observations and numerical results.

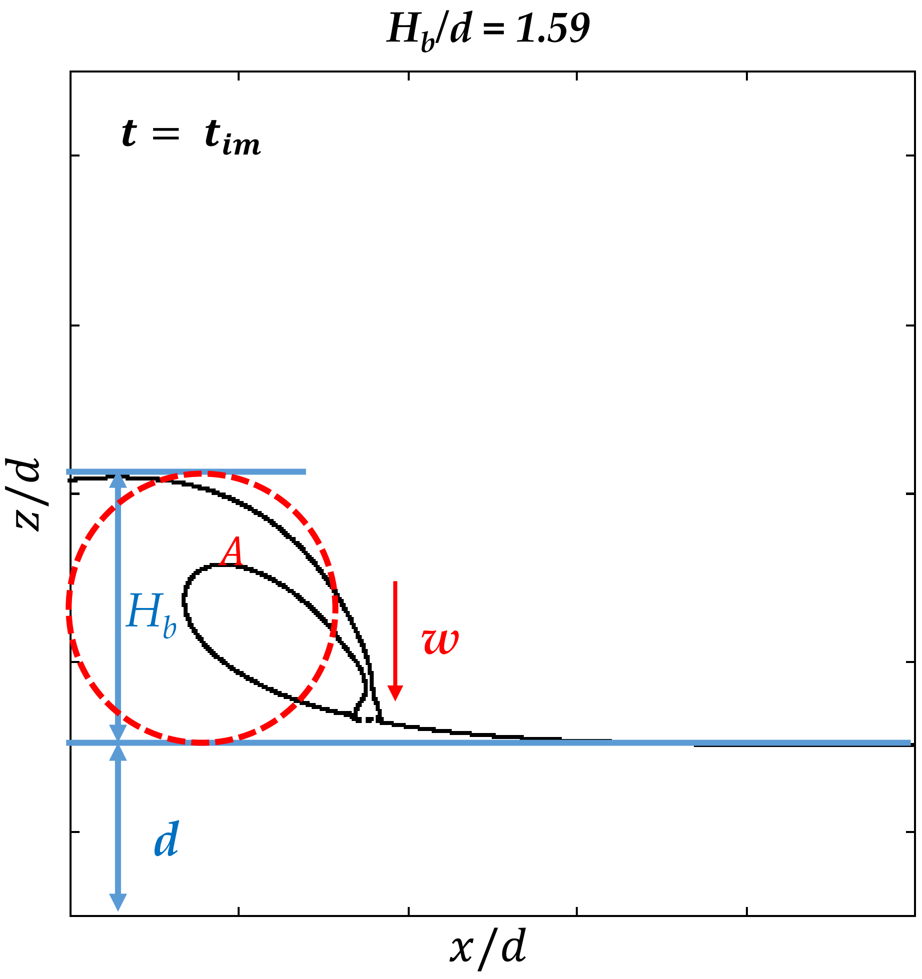
Inertial model for shallow water breaking waves





The mixing zone is not bounded by the depth, implying that the representative length scale l should be scaled by H_b.

Inertial model for shallow water breaking waves



Free fall assumption:

$$w = \sqrt{2gH_b}$$

Inertial estimate for the dissipation per unit mass:

$$\epsilon = \chi\left(\frac{w^3}{H_b}\right) = \chi(2g)^{3/2}\ {H_b}^{1/2}$$

Dissipation per unit length of wave crest:

$$\epsilon_l = \rho A \epsilon = \chi \frac{\pi}{\sqrt{2}} \rho g^{3/2}\ {H_b}^{5/2}$$

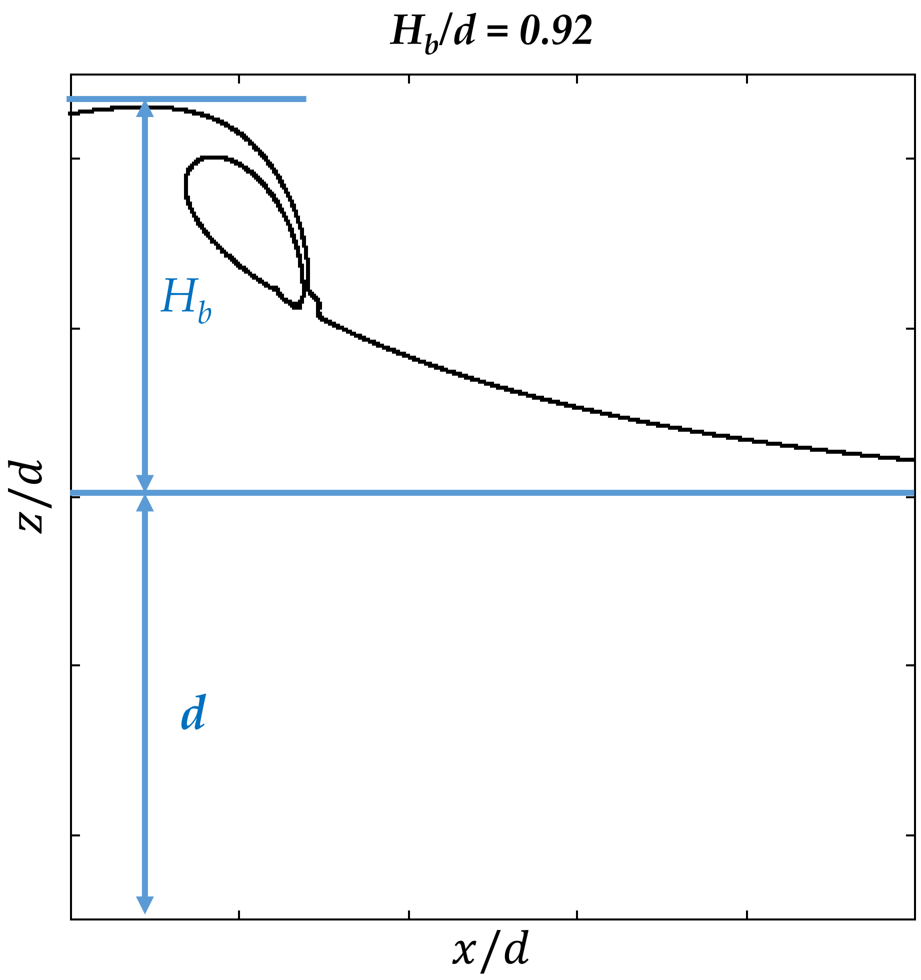
where $A \approx \pi {H_b}^2/4$ by assuming a cylindrical turbulence cloud

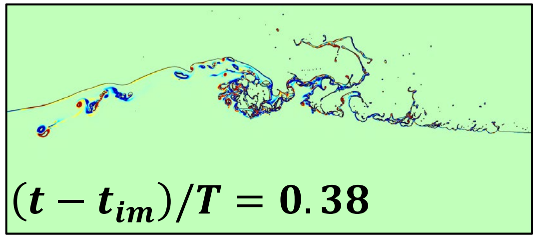
Breaking parameter:

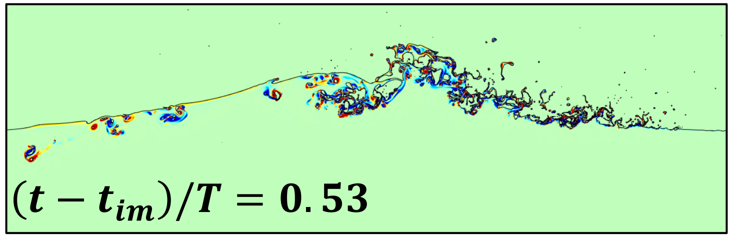
$$b = \frac{\epsilon_l g}{\rho c^5} = \frac{\epsilon_l}{\rho g^{3/2} d^{5/2}} \propto \left(\frac{H_b}{d}\right)^{5/2}$$

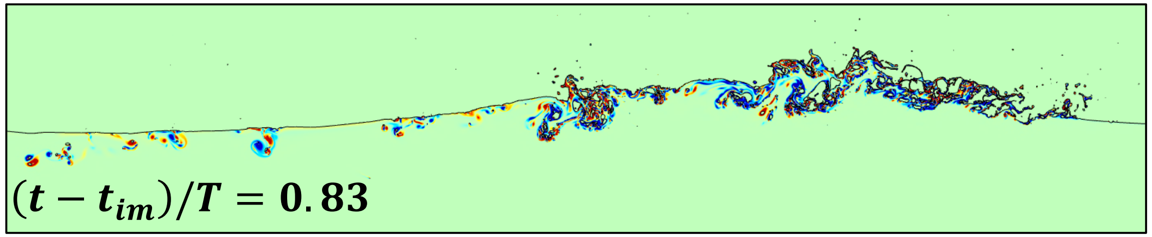
where $c = \sqrt{gd}$ by dispersion relation in shallow water

Inertial model for shallow water breaking waves

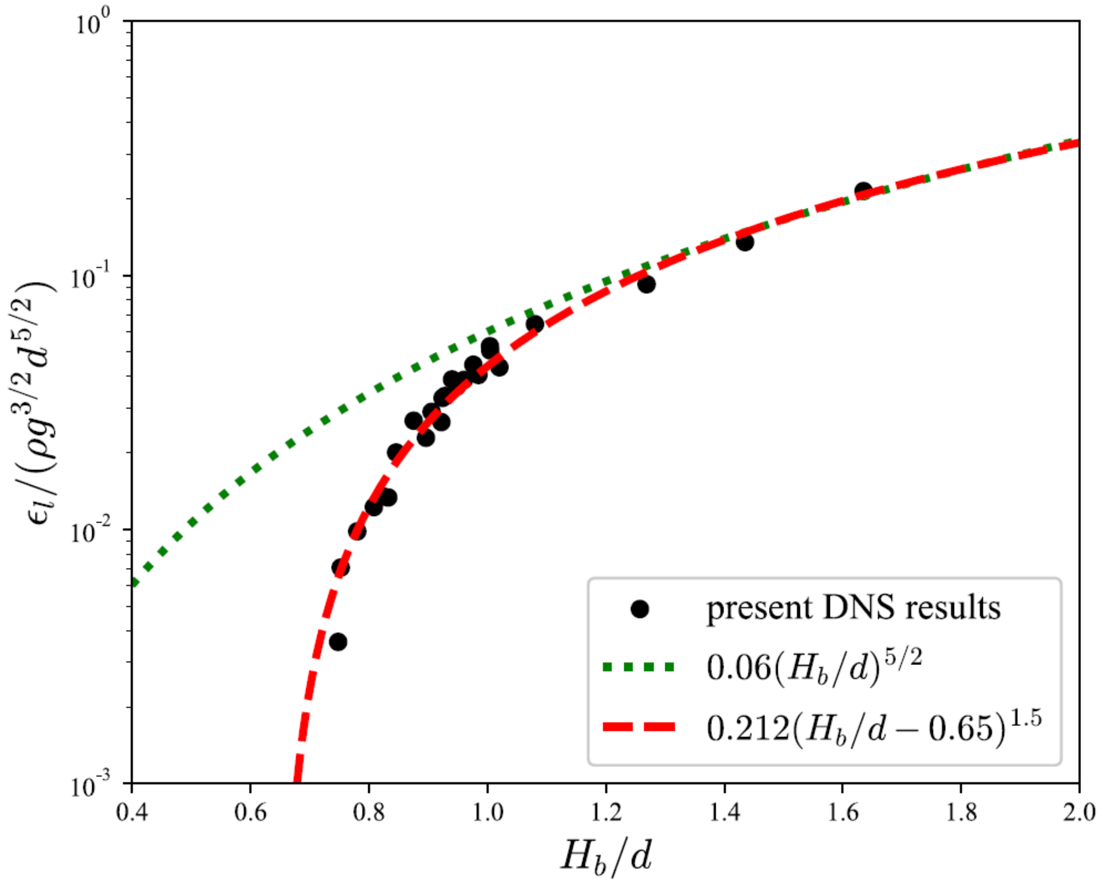








Breaking strength scaling



Breaking parameter b as a function of H_b/d. Dotted line: inertial scaling of b $\propto (H_b/d)^{5/2}$. Dashed line: empirical scaling of b $\propto (H_b/d - 0.65)^{1.5}$ by introducing a threshold. Data from the present 2D DNS results.

Conclusion

- **Reproduction of the experimental waves**
- **Wave type classification by the wave height**
- **Dependence of the Bond number on the main cavity size**
- **Relationship between breaking parameter b and the local breaking height**

Thank you!
Questions?