# COMPARISON OF FLOW DYNAMICS AND AIR ENTRAINMENT UNDER LABORATORY PLUNGING AND SPILLING BREAKING WAVES

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## INTRODUCTION

Wave breaking plays a vital role in enhancing transfer of mass, momentum, and energy across the air-sea interface. Even though wave breaking has been intensively studied, a vast part of the air entrainment process is still poorly understood. One major reason is that multiphase approaches considering air-water mixture density variation have rarely been used. To quantify certain flow properties that involve air entrainment and fluid density variation, such as the mean and turbulent kinetic energy as well as potential energy under breaking waves, void fraction measurements are essential.

In the present study, through combined velocity and void fraction measurements, flow kinematics, turbulence, void fraction, and the effects of void fraction to energy dissipation were investigated. The data uniquely characterize and compare kinematic and dynamic properties of the multiphase flow, including flow structure in the highly aerated region, under plunging and spilling breaking waves.

## EXPERIMENTAL SETUP

The experiment was performed in a two-dimensional wave tank (length: 35 m; width: 0.91 m; depth: 1.2 m) located in the Department of Civil Engineering at Texas A&M University. A wave focusing technique was employed to generate a single plunging (spilling) breaking wave with a breaking wave height of $H$ = 0.204 m (0.265 m), a wavelength of $L$ = 1.08 m (1.84 m) in a wave train under a deep water condition. The origin $x$ = 0 and $t$ = 0 are defined at the impinging point (breaking point) and $z$ = 0 at the still water level as shown in Figure 1. A modified particle image velocimetry (PIV) technique was employed to measure the velocity fields including the entire aerated region, while fiber optics reflectometry (FOR) was used to measure void fraction under both the breaker types. For PIV measurements, 14 (24) fields of view (FOV) were used, as shown in Figure 1, with 20 repeated tests in each FOV to reconstruct the flow field and obtain mean and turbulence statistics through ensemble averaging. In addition, FOR measurements were conducted at 3 cross sections at $x/L$ = 0.40, 0.81, 1.11 ($x/L$ = 0.50, 1.00, 1.55) with a vertical spatial resolution of 10 mm.

## RESULTS AND DISUCSSION

One of the criteria for predicting breaking onset is through energetic threshold. Barthelemy *et al.* (2018) proposed a criterion where $B$ is defined as the ratio between the local energy flux and the local energy density projected on the wave propagation direction, and $B_{th}$ is the threshold value of $B$ at which the wave begins to break. In the present study, $B$ was calculated based on the measured horizontal velocity at the crest peak divided by the phase speed $C$ calculated from the linear wave theory. In the current study, the measured $B$ sharply increases near the breaking onset of $B_{th}$ = 0.85 under both the plunging and spilling breaking waves. In addition, recorded high-speed video images reveal that a small-scale impinging/splash-up occurred in the process which is likely to cause of the multiple threshold crossings of $B$ (not shown for brevity).

Figure 2 shows the spatial variation of potential energy ($PE$), total kinetic energy ($KE$ = mean + turbulent kinetic energy), and total energy ($KE + PE$) accounting for void fraction. The wave energy variation considering void fraction under plunging (spilling breakers) may be formulated as $E_\alpha/E_L = 1.47e^{-1.17x/L}$ for $x/L > 0.33$ ($E_\alpha/E_L = 1.06e^{-0.55x/L}$ for $x/L > 0.1$).

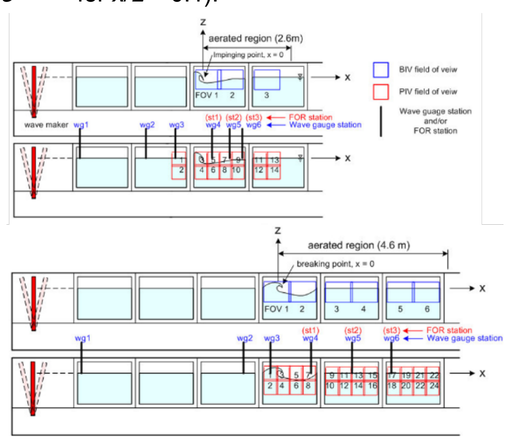


Figure 1 - Schematic diagram of the wave tank and instrument configuration including 14 PIV FOVs for plunging and 24 PIV FOVs for spilling breaking waves.

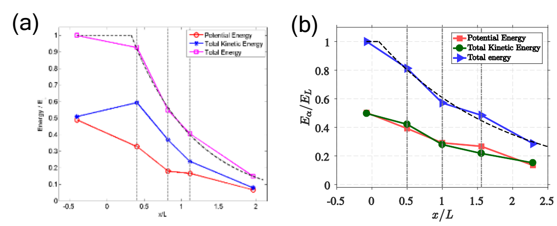


Figure 2 - Spatial variation of total wave energy ($E_\alpha = KE + PE$) accounting for void fraction normalized by the corresponding pre-breaking wave energy ($E_L$) for the (a) plunger and (b) spiller. The dashed line for $E_\alpha / E_L$ is from the empirical formula (a) $E_\alpha/E_L = 1.47e^{-1.17x/L}$ for $x/L > 0.33$ and $E_\alpha/E_L$ =1.0 for $x/L \leq 0.33$ for the plunger and (b) $E_\alpha/E_L = 1.06e^{-0.55x/L}$ for $x/L > 0.1$ and $E_\alpha/E_L$ =1.0 for $x/L \leq 0.1$ for the spiller.

## REFERENCES

Barthelemy, X., Banner, M. L., Peirson, W. L., Fedele, F., Allis, M., & Dias, F. (2018). On a unified breaking onset threshold for gravity waves in deep and intermediate depth water. *Journal of Fluid Mechanics*, 841, 463-488.