

## Observation of the coherent turbulent structure under breaking wave

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### ABSTRACT

Previous studies qualitatively sketched that relative larger coherent turbulent motions generated in the crest region would stretch downward into the trough level during propagation of breaking wave in the surf zone. This event further suggests that an instantaneous burst of turbulence intensity will occur locally in the path of the penetrating turbulent motion. To observe such a spatial depended turbulent structure, the internal flow field of spilling wave propagating on an inclined bottom slope of 1/20 was measured quantitatively by Particle Image Velocimetry. The ensemble average method is employed to decompose the mean flow and turbulent fluctuations by repeating the same experiment for twenty-five times in each Field of View (FOV). Seven FOVs were integrated for representing the global results, which covers the breaking wave from the outer to inner surf zones. The temporal and spatial evolutions of the coherent turbulent structure were examined and discussed. Results manifest that a relative large turbulent motion is initially organized in the wave crest of the bore-established region. As the wave crest passed, this turbulent structure will then stretch downward to the interior region of the water column. Two important dynamic turbulence transport terms, the turbulent convection and diffusion, were estimated to investigate the underline mechanism of the turbulence transport. It is found that the convection term is much significant to spread the turbulent structure from the wave crest to trough region.

**KEY WORDS:** turbulence, turbulent transport, surf zone, spilling wave, PIV

### INTRODUCTION

The hydrodynamics of breaking waves in the surf zone has been an important subject for coastal and environmental engineering. Detailed reviews on hydrodynamics in the surf zone can be found in Peregrine(1983), Battjes (1988) and Christensen et al. (2002). Flow visualization is a powerful technique to experimentally investigate

qualitative flow structures of wave breaking. For instance, Nadaoka et al. (1989) found the generation of oblique descending eddies under breaking waves by this technique. Lin and Hwang (1992) employed a fluorescent dye illuminated by an ultraviolet lamp to exhibit the motion of the surface roller, the bubble-mixing process, and the vortex stretching of plunging breakers. Additionally, experimental studies providing quantitative details have been carried out for decades. Svendsen et al. (1978) focused on the variation of surface profiles using a wave-gauge technique. Investigations on the internal flow of breaking waves using Laser Doppler Velocimetry (LDV) were reported by Stive(1980), Nadaoka and Kondoh (1982), Ting and Kirby (1996) and Stansby and Feng (2005). Although LDV provides the advantage of a high sampling rate on a fixed point, it is difficult to provide a complete evolution of flow structures in the surf zone.

In recent years, PIV has been used frequently due to its full-field map of velocity. An exhaustive guide on the development of the PIV system and its applications to water waves can be found in Raffel et al. (1998) and Grue et al. (2003), respectively. Although PIV is a more effective flow measurement technique than LDV, the spatial resolution and frame rate are still limited so that it is not satisfactory for the research of breaking waves. For example, Chang and Liu (1999) measured the kinematics of breaking waves at an intermediate constant water depth. Their results focused on the range of one single frame at the breaking location. Oblique descending eddies were investigated in the spanwise plane by Cox and Anderson (2001), Son and Kihm (2001) and Watanabe et al. (2006). However, the flow induced by wave breaking evolves broadly on a sloping bottom from breaking point to the inner surf zone. It is difficult to display the flow evolution from a local fixed measurement of PIV. In order to understand the evolution of internal flow in surf zone, the PIV measurements should be integrated from several different positions as given by Qiao and Duncan (2001), Melville et al. (2002) and Kimmoun and Branger (2007).

The main purpose of this study is to investigate the evolutional flow structures of breaking waves in the surf zone using PIV. In the past, quantitative results by LDV only provided physical information at