Turbulence analysis in breaking waves

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Two different types of breaking waves, a spilling and a plunging one, are examined, while propagating in the surf zone along a sloped (1:20) impermeable and fixed bottom. They were reproduced in the laboratory wave channel of the DICATECh Department, that is 45 m long and 1 m wide, with the water depth close to the generator kept equal to 0.7 m. The main features of the waves are shown in Table 1, being H_0 the wave height at the wave paddles, T the wave period, L_0 the wavelength according to Airy theory and ξ_0 the Irribarren number. The velocity field was measured by using a backscatter, two-component four-beam fibre-optic LDA system, and the free surface profile was assessed using resistance probes. Figures 1a and 1b show a part of the wave channel and the measuring system.

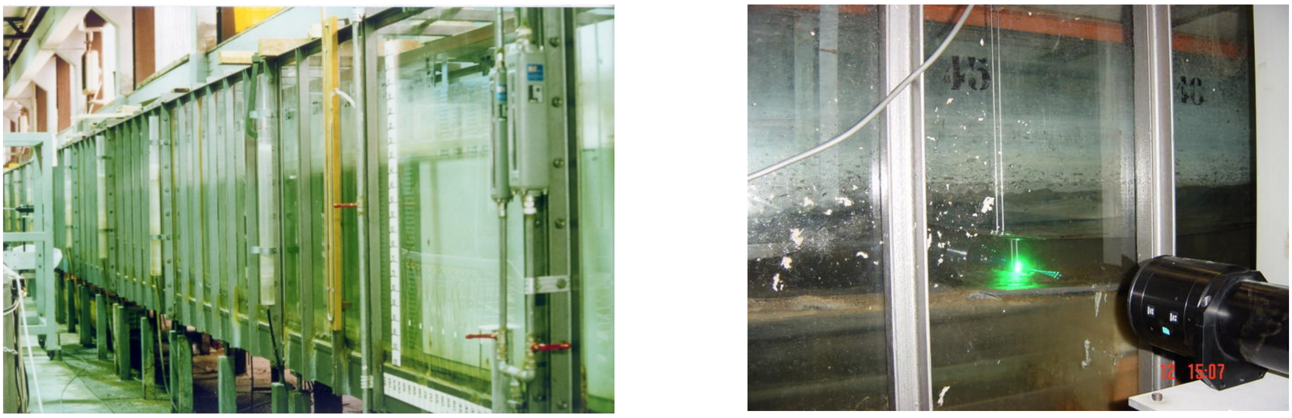

Figure 1. Experimental apparatus: a) a part of the wave channel and b) the LDA probe.

Specifically, we analyze the power spectra of the turbulent longitudinal and vertical velocities (u' and w' respectively) assessed in selected vertical sections of the surf zone, at three different depths, i.e., close to the bottom, at mid-depth and near the surface (Figure 2a). In this way, we can detect some frequency regions where: i) the decrease in energy almost follows a slope -1, which is indicative of a coexisting energy production and cascade energy transfer (Nikora, 2005); ii) the spectrum shows peaks with a -3 slope, corresponding to quasi 2D large coherent structures (Truong et al., 2018); iii) the slope of the spectrum almost follows -5/3, thus is typical of the inertial subrange. Such information, examined along the longitudinal and vertical directions in the breaking zone, seems useful to describe the turbulent behavior of the waves. Furthermore, by considering the autocorrelation functions of the fluctuating velocities, the integral and turbulent length scales are also computed.

As a second step, we use the Weakly-Compressible Smoothed Particle (WCSPH) model, coupled with a Sub-Particle Scale (SPS) approach to modeling turbulence, for reproducing numerically the waves. Preliminary comparisons of the above-mentioned spectra show a good agreement (Figure 2b). The Okubo–Weiss parameter W rated by $W_0=0.2\sigma_W$, with σ_W being the standard deviation of W in the whole domain, allows to separate the flow into different regions, i.e., a vorticity-dominated region, a strain-dominated region, and a background field.

Furthermore, the obtained numerical flow fields can therefore be used to investigate the characteristics of breaking vorticity within these flows. In Figures 3 and 4 snapshots of W/ W_0 and vorticity ω are shown in the 2-D longitudinal section for the plunging case, during and after breaking. During breaking, due to the impact of the jet on the surface, positive vorticity is generated and propagates with the uprush flow, while negative vorticity spreads in the return flow at intermediate depths. After breaking (Figure 4b), positive vorticity largely persists at the surface in the wave bores, while negative vorticity rapidly decreases. The maps of W/W_0 highlight the dominance of strain during breaking (Figure 3a); instead, after breaking (Figure 4a) some coherent structures seem to propagate obliquely towards the bottom.

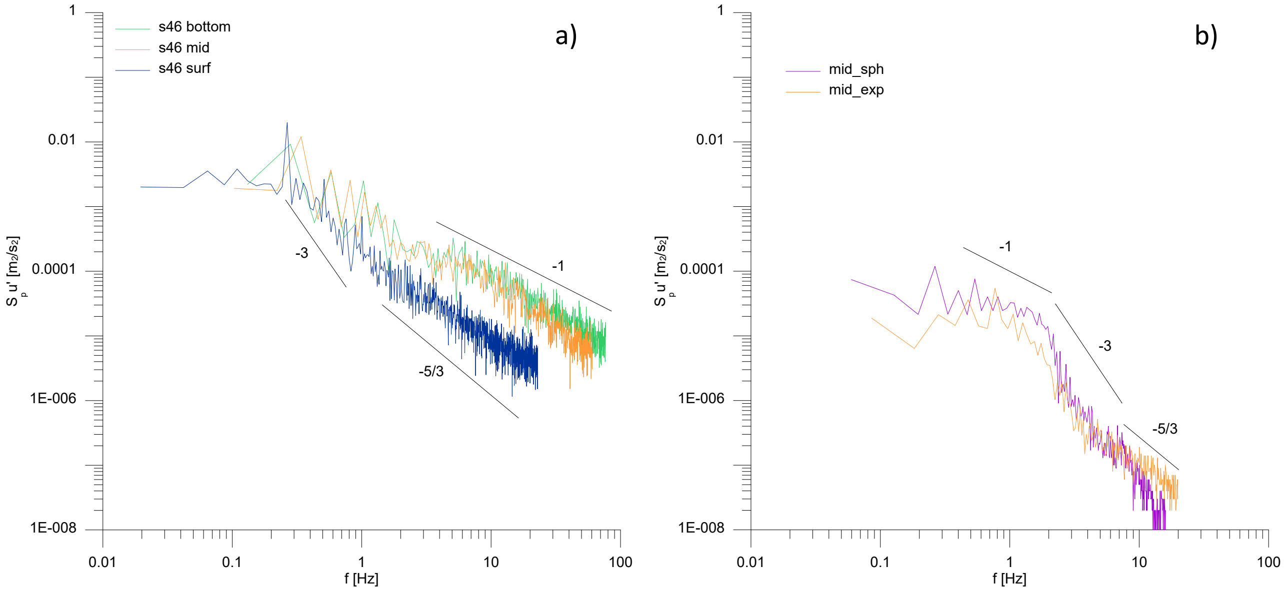

Figure 2. Power spectra of *u′* for the plunging wave case T2: a) in a section onshore breaking, close to the bottom (green), at mid-depth (orange) and near surface (blue); b) in a section in the breaking region, at mid-depth, comparing SPH results and experimental data.

Table 1. Experimental parameters of the analyzed regular waves**.**

	H_0 (cm)	T (s)	L_0 (m)	ξ_0	***Breaking type***
T1	11	2	4.62	0.37	spilling
T2	6.5	4	10.12	0.74	plunging

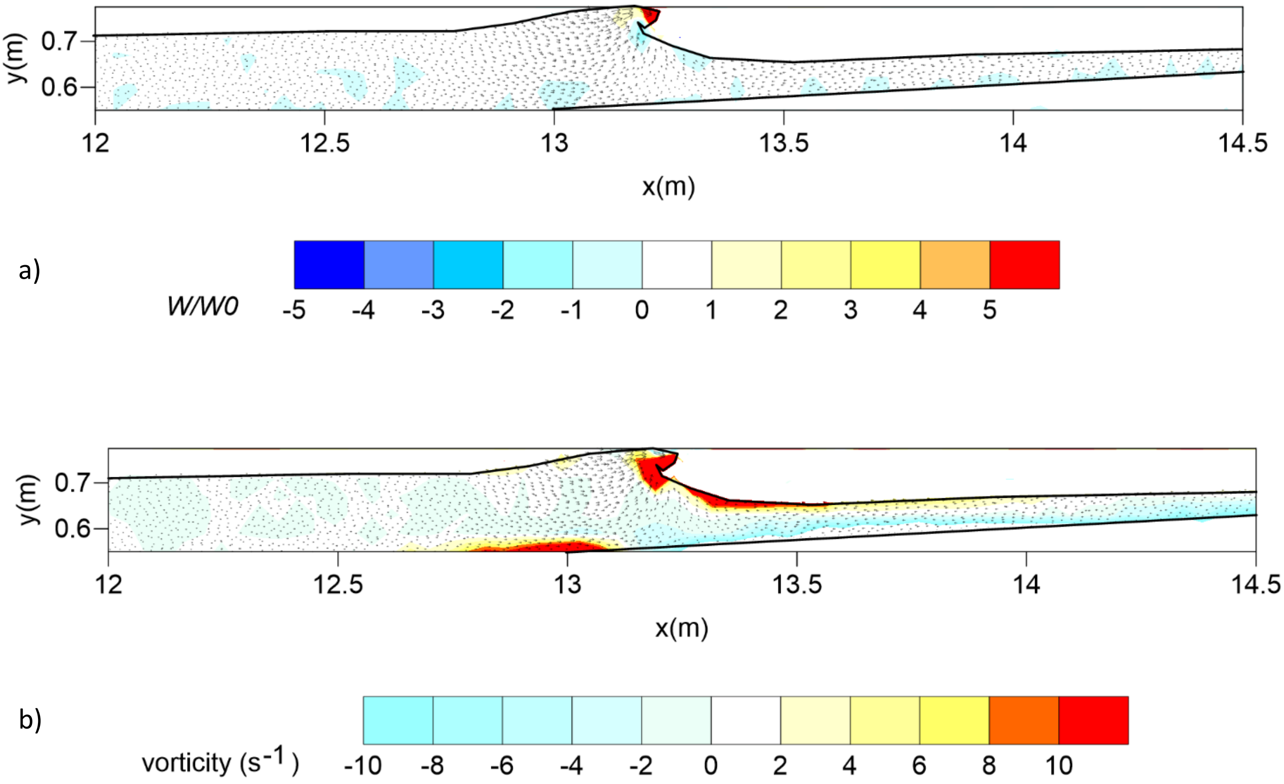

Figure 3. Snapshots of a) W/W_0 and b) vorticity field for the plunging wave test T2 during breaking

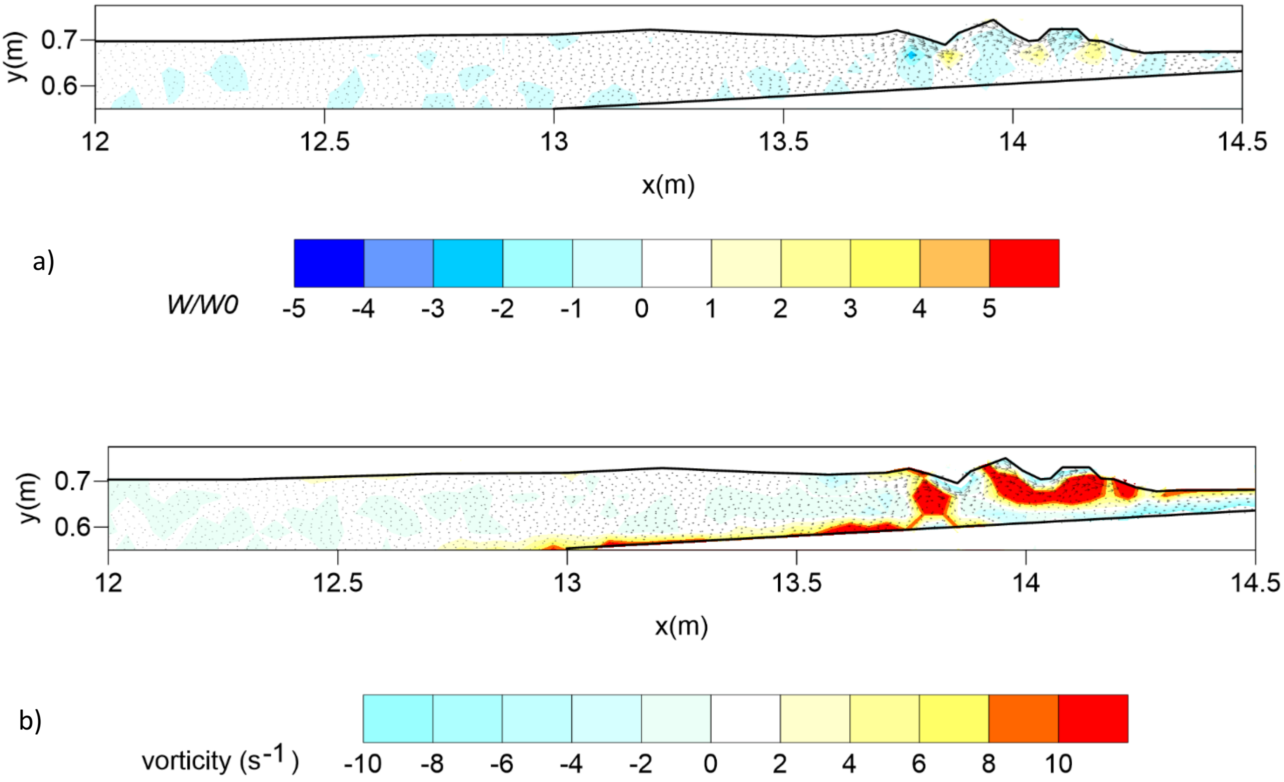

Figure 4. Snapshots of a) W/W_0 and b) vorticity field for the plunging wave test T2 after breaking

References

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