PLUNGING WAVES IN THE INNER SURF ZONE AND BURGERS-LIKE TURBULENCE

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PROBLEM STATEMENT

It is well known that the nearshore circulation plays a significant role in shaping beaches across various time and spatial scales. It also has a substantial impact on the movement of sediments, pollutants, nutrients and even microplastics across the shore, driving their net transport and determining patterns and transport rates, also causing disruption to coastal ecosystems. How such processes of mixing, dispersion and transport are associated to the turbulent energy produced by wave breaking is investigated since long, because of its great relevance, but is still far from being completely understood, thus needing more analysis.

Moreover, extensive experimental and numerical investigations have predominantly focused on the outer surf zone, which is the region where the wave breaking occurs (Kimmoun and Branger, 2007; De Serio and Mossa, 2006, 2019). They have identified that the structure and intermittency of the surface generated turbulence are highly dependent on the breaker type. In spilling breakers, turbulence tends to be confined to the upper portion of the water column due to the relatively small size of the eddies generated (Ting and Kirby, 1995). However, Nadaoka et al. (1989) in their pioneering work also observed turbulence spreading downward, forming obliquely descending eddies behind the wave crest. Over a wave cycle turbulence is fairly homogeneous and generally transported seaward (Ting and Kirby, 1995; De Serio and Mossa 2006). In plunging breakers turbulence is characterized by downburst vortices, that is counter-rotating vortices extending obliquely downward, generated by the impinging jet (Watanabe et al., 2005; Lubin and Glockner, 2015), This results in large mixing lengths and more homogeneous turbulence intensities in the vertical profile.

On the contrary, as also underscored by Brinkkemper et al. (2016), more studies are needed for the inner surf and swash zones, which represent the connection for sand exchange between deeper water and the beach, thus being of high importance for beach management and restoration projects. In the present research we focus on the inner surf zone, which can be defined as the surf subsection of transition between the wave breaking area and the swash zone, the last one being the zone where wave-driven flows alternately wash up and down the beach face (Brinkkemper et al., 2016), At the breaking point and immediately after breaking, waves display steep faces, and strong vertical accelerations revealing the significance of non-hydrostatic effects in this particular region. Conversely, within the inner surf zone, non-hydrostatic processes are generally considered to be negligible. This is primarily due to the resemblance of broken waves to bores, wherein the pressure field closely approximates hydrostatic conditions (Madsen and Svendsen, 1983). It should also be noted that in the inner surf zone, waves are strongly nonlinear and almost non-dispersive. These nonlinear and dissipative processes seem to generate shock waves, having a sawtooth shape. Starting from the nonlinear nondispersive shallow water equations, using the diffusive shock approach, the Burgers' equation is obtained in the hypothesis of gentle slope (Bonneton, 2022).

Therefore in this study we especially examine the turbulent energy spectra of two laboratory waves, a plunging one and a spilling-plunging one in the inner surf zone, with the aim to verify if Burger's turbulence model can be applied, especially considering that it is used in situations where the one-dimensional approximation is deemed appropriate, In detail, we investigate how turbulent energy spreads and dissipates involving different length scales in the inertial and diffusive range. It is worth remarking that applying relations of Burgers turbulence could lead to modelling simplifications and easier mathematical solutions, in the prediction of wave energy dissipation in the inner surf zone. This is a valuable result in our opinion.

METHODS AND RESULTS

Two different types of regular breaking waves are examined, while propagating in the inner 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 45m long and 1m wide, with the water depth close to the generator kept equal to 0.7m. They were already investigated in a previous work by De Serio and Mossa (2006), but only referring to the shoaling and outer surf zone. They are i) a spilling-plunging (SP) wave with height H=12.1cm, period T=2s and length L=2.29m at breaking, ii) a plunging (P) wave, with height H=12.6cm, period T=4s and length L=4.66m at breaking.

The velocity field was measured by using a backscatter, 2D Laser Doppler Anemometer, and the free surface profile was assessed at same time and locations using resistance probes. De Serio and Mossa (2006) can be referred to for experiments' details.

A qualitative analysis of the elevation time series measured onshore the breaking section shows for both SP and P waves a typical sawtooth shape (Fig. 1), which drove us to perceive them as shock waves propagating in shallow waters with a celerity $c=(gh)^{0.5}$, where h is the local depth.

Referring to the time series of the measured u velocity component (i.e., the cross-shore one), we used the

phase-averaging technique to extract the turbulent fluctuation u'. After this, by processing such signal with FFT, the corresponding turbulent power spectrum was obtained. This procedure was executed for each wave (SP and P) and for all the points investigated along different vertical profiles onshore the breaking section (xb=0, being x the horizontal axis directed towards the shore),

For the sake of brevity, the results at x=1.3m from xb, show that for the SP wave, at the highest frequencies spanning [1÷20] Hz, the spectrum exhibits a slope -2, consistent with Burger turbulence theory. So at small scales turbulence dissipate as in 1D shock waves. At frequencies lower than 1Hz, that is at large scales, bed generated turbulence dominates yielding the −1 spectral law (Nikora, 1999). This trend is observed across almost all points in the vertical profile, each spaced 1 cm apart. Fig. 2 figure illustrates points in close proximity to both the surface and bottom, serving as an example (with 'z' denoting the vertical coordinate starting from the bottom and moving upward). For the P wave, analogous spectra are displayed in Fig. 3, showing a very similar behavior with the SP wave case. In the P wave, the injection of bed generated turbulence is more evident at larger scale than in SP, while at small scales turbulent energy cascades again with -2 slope.
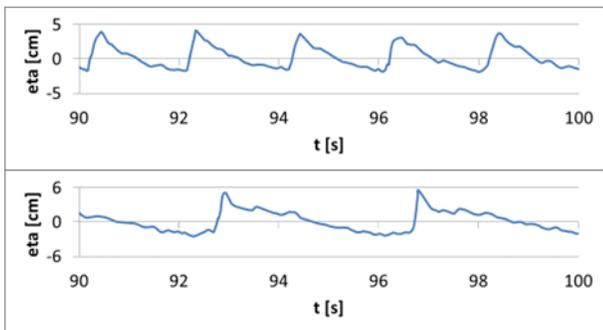

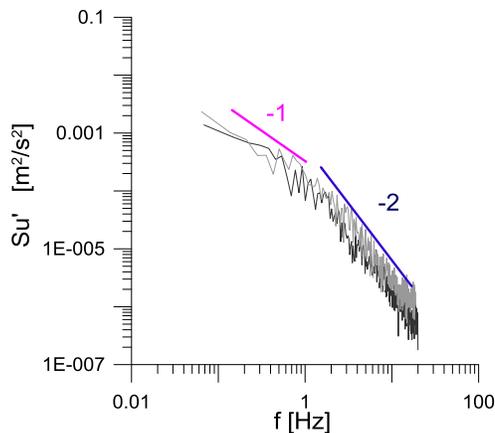Figure 1 – Extract of time series data showing measured elevation (eta) at x=1.30m onshore xb for SP wave (top) and P wave (bottom)

Figure 2 – SP wave: Energy power spectra of turbulent horizontal velocity u' at x=1.30m onshore xb. Dark gray: close to bottom (z/h=1.5); light gray: close to surface (z/h=0.71)

(z/h=0.71)

As a preliminary result, we can state that the 1D Burgers turbulence model seems reliable in the assessment of inner surf zone turbulence. Nevertheless, other investigations are needed to make this approach of broader applicability.
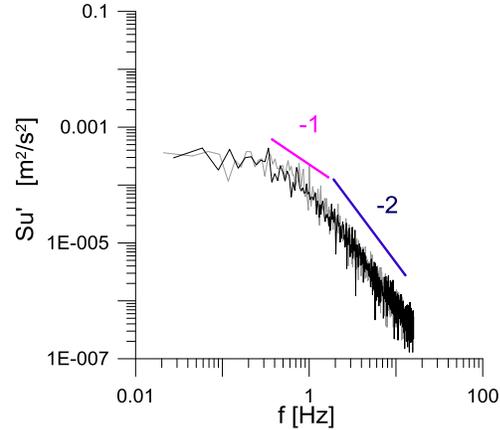

Figure 3 – P wave: Energy power spectra of turbulent horizontal velocity u' at x=1.30m onshore xb. Dark gray: close to bottom (z/h=1.5); light gray: close to surface (z/h=0.71)

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