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Toward a Universal Model of Breaking Waves on Shallow Water

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ABSTRACT

If a wave approaching the coast is long and the variation of the coastal slope is gradual, spilling breakers usually appear. They are characterized by the appearance of a finite turbulent fluid zone riding down the forward slope of the wave (LonguetHiggins \& Turner, 1974, Duncan, 2001). At the toe of this turbulent zone the wave slope changes sharply, resulting to the flow separation and the vorticity creation. The breaking waves entrain the air the water by forming whitecaps' where an intensive dissipation occurs. Such a turbulent zone has a strong influence on the wave evolution.

As it was mentioned in Duncan (2011), theoretical models of spilling breakers are rare. Indeed, beyond the multiphase aspects, the modelling depends crucially on a precise description of the flow structure. In the case where the flow potentiality is supposed, one actually uses an interesting approach based on a coupling between the dispersive GreenNaghdi equations describing waves far from the coast, and the hyperbolic Saint-Venant equations near the coast (cf. Tissier {\it et al.} (2012)). The difficulty is to understand when we replace one model by another one. A search of such a `switching criteria' is not a well defined problem even if several empirical criteria were proposed in the literature (wave phase velocity becomes larger than the flow velocity, or the wave slope attains a critical value, for example).

The main issue of our work is a two-layer modelling, where the upper turbulent layer is considered within the framework of shear shallow water flows (cf. Teshukov, 2007, Richard \& Gavrilyuk, 2012, 2013, Castro \& Lannes, 2014), while the lower layer is potential and can be described by a GreenNaghdi type model. The interaction between layers is taken account through a natural mixing process, where the mixing velocity is proportional to the intensity of large eddies of the upper layer. Experimental data on the structure of the turbulent flow field under breaking waves show that the frontiers between the turbulent region caused by the wave breaking and the potential region are clearly visible (Nadaoka {\it et al.} 1989, Lin \& Rockwell, 1994). This justifies a two-layer scheme for the modelling of the breaking waves. The model generalizes that derived in Liapidevskii \& Chesnokov (2014) where the hydrostatic approximation in both layers was used, and that in Richard \& Gavrilyuk (2015) where such a two-layer approach was used in the limit where the thickness of the upper shear layer was vanishing.

In particular, we show that our model is able to describe the transition from undular to breaking bores when the Froude number varies between \$1.3\$ and \$1.4\$. The shoaling and the breaking of solitary waves on mild slopes is also well predicted by the model.