



Babanin, A. V. (2008). Wave breaking: do we know why the waves break?

Paper presented at the *Topical Problems of Nonlinear Wave Physics International Symposium (NWP 2008)*, Nizhny Novogord, Russia, 20-26 July 2008

Copyright © 2008 Alexander Babanin.

This is the author's version of the work. It is posted here in accordance with the copyright policy of the publisher for your personal use. No further distribution is permitted.



WAVE BREAKING: DO WE KNOW WHY THE WAVES BREAK?

A. V. Babanin¹

¹ Swinburne University of Technology, Melbourne, Australia, e-mail: ababanin@swin.edu.au

Wave breaking provides one of important feedback means in the air-sea interactions, whose role is most efficient and significant at extreme conditions. This role encompasses a variety of feedback mechanisms, in response to the wind forcing, which include alteration of the sea drag, control of the wave height, negotiation of the air-sea exchange of mass, energy and momentum, as well as a source of the upper-ocean turbulence responsible for the ocean mixing.

But why do ocean waves break? The breaking of deep-water surface water waves represents one of the most interesting and challenging problems of fluid mechanics. Breaking is a strongly nonlinear shock-like intermittent random process, the distribution of which on the water surface is not continuous. The role breaking plays in maintaining the energy balance in continuous air-sea interaction field is, however, critical.

Understanding this important and obvious property of the ocean surface has been elusive for decades, and therefore rather arbitrary parameterisations have usually been employed to parameterise the breaking-related processes. Over the past years, however, there has been a significant progress in understanding and description of the wave breaking probability (e.g. Babanin et al., 2001, 2007a), modulational behaviour of 2D nonlinear groups leading to wave breaking (Waseda and Tulin, 1999, Brown and Jenkins, 2001, Onorato et al., 2002), properties of the breaking onset of two-dimensional waves (e.g. Babanin et al., 2007b, 2008). The overall picture of the breaking in realistic field conditions, however, and the mixing/dissipation caused by the breaking in the ocean, is still incomplete due to two main reasons: lack of understanding of the breaking behaviour in three dimensions, where the nonlinear modulational process is known to be weakened (Brown and Jenkins, 2001, Onorato et al., 2006), and without description of the breaking severity as a function of wave and environmental characteristics (Babanin et al., 2008).

The paper will discuss the present state of wave-breaking research, both recent advances and current limitations. The very definition of the breaking onset, methods of breaking detection and different breaking processes need to be scrutinised. Because the breaking is routinely detected when it produces whitecapping, and the whitecaps are produced in the process of the breaking collapse, traditionally the initial phases of a breaker-in-progress are treated as incipient breaking. Variety of geometric, kinematic and dynamic criteria for the breaking onset has been suggested over the years, based on the studies of these phases of the wave collapse. We argue that these stages are not suitable for investigating the cause of the breaking because dynamics of the water surface collapse after the breaking started is different to the dynamics of the water waves leading to the breaking.

In detail, a study of the wave breaking onset due to natural evolution of steep two-dimensional waves will be described. The numerical/experimental study investigated the properties and the causes of breaking of two-dimensional waves in deep water. The progression of initially monochromatic steep waves to the point of breaking was first approached by means of the fully nonlinear Chalikov-Sheinin model. Particular attention was paid to the evolution of nonlinear wave properties, such as steepness, skewness and asymmetry, whose behaviour are possible to verify in the physical space, i.e. in experiment, and to their interplay leading to breaking onset. Individual wave steepness was found to be the single parameter which determines whether the wave will break immediately, never break or take a finite number of wave lengths to break.

The addition of wind forcing can play multiple roles in changing the wave-breaking dependences. Instantaneously, wind was found to only have a marginal effect on the breaking onset, unless the wind forcing is very strong. Wind action is, however, important on longer scales in altering wave steepness and thus the breaking statistics.

The results were subsequently verified and expanded in a laboratory experiment. The experiment demonstrated good qualitative agreement with the numerical simulations and consequently properties of the breaking onset and the breaking dependences were quantified. These experiments also revealed a number of new features of the nonlinear wave development near breaking, i.e. reduction of the wave period prior to breaking and dependence of the wave energy loss on the wind forcing. The latter dependence is driven by the wind's ability to alter the depth of the non-linear wave modulation.

It was shown that the breaking will occur once the wave reaches a value close to the Stokes limiting steepness. In reality, this value can be either achieved as a result of non-linear growth of sideband

instabilities as in the above-mentioned experiment, or occur because of linear superposition of narrow-banded waves. The limiting steepness of the pre-breaking wave in the latter case appears to be the same (Brown and Jenkins, 2001).

The breaking processes, initiated by the two different mechanisms, however, differ and bring about different outcomes in terms of the wave energy dissipation: energy loss and distribution of this loss across the spectrum are dissimilar. In case of breaking caused by the modulational instability, most of the energy loss comes from the primary wave, whereas in the case of linear superposition energy is lost almost entirely from the higher frequencies whereas the spectral peak remains unchanged after breaking (Meza et al., 2000). This conclusion has significant consequences for wave dissipation studies: i.e. research on breaking and dissipation have to be separated. While any process which leads to the critical steepness will cause the wave to collapse, the end result in terms of the spectral dissipation will have differences.

Such distinct difference also allows to underpin the likely mechanism which causes the breaking in the field. Under field conditions, it was observed that when the dominant waves break they lose some 30% of their energy and a similar amount of energy is also lost proportionally across the spectrum, the so-called cumulative effect (Young and Babanin, 2006). Such observation suggests the modulational instability, rather than wave superposition, as a likely reason for wave breaking in the field. Apart from the cumulative effect, a number of other features of nonlinear wave behaviour leading to breaking is consistent with the field observations. Among them, double-breaking found in the laboratory experiments and observed in the field, upshifting of spectral energy, oscillations of the skewness/asymmetry, pre-breaking wave-length decrease, quadratic dependence of the breaking probability on the wind speed. Although all of these effects provide only indirect confirmations in favour of the non-linear modulational instability, the very quantity of them is significant.

The modulational instability, however, is significantly impaired in the directional wave fields as has been shown in most recent laboratory experiments by Onorato et al. (2008) and Waseda et al. (2008). These results have a particularly significant implications for the higher-frequency tail of the wave spectrum. At the tail, the directional spread of wave energy is broader and the wave process is not narrow-banded, which means that the modulational instability as a mechanism causing breaking of short waves is unlikely. Most feasibly, breaking of such waves is induced by the dominant waves, either because of the dominant breaking or due to modulation of short waves by longer waves. Therefore, the question of the causes for the breaking of three-dimensional spectral waves still remains open.

References

1. A.V. Babanin, I.R. Young, and M.L. Banner, 2001, Breaking probabilities for dominant surface waves on a finite constant depth. *J. Geophys. Res.*, **106**(C6), 11659-11676.
2. A.V. Babanin, I.R. Young, R. Manasseh and E. Schultz, 2007a, Spectral dissipation term for wave forecast: an experimental study, *Proc. 10th International Workshop on Wave Hindcasting and Forecasting and Coastal H Oahu, Hawaii, November, 11-16, 2007*, 19p.
3. A.V. Babanin, A.V., D. Chalikov, I.R. Young, and I. Savelyev, 2007b, Predicting the breaking onset of surface water waves. *Geophys. Res. Lett.*, 2007, **34**, L07605, doi:10.1029/2006GL029135, 6p.
4. A.V. Babanin, A.V., D. Chalikov, I.R. Young, and I. Savelyev, 2007, Breaking of nonlinear two-dimensional waves in deep water, *J. Fluid Mech.*, 2008, submitted.
5. M.G. Brown, and A. Jensen, 2001, Experiments in focusing unidirectional water waves. *J. Geophys. Res.*, **C106**, 16917-16928.
6. Chalikov, D., and D. Sheinin, 2005, Modeling extreme waves based on equations of potential flow with a free surface. *J. Comp. Phys.*, **210**, 247-273.
7. E. Meza, J. Zhang, and R.J. Seymour, 2000, Free-wave energy dissipation in experimental breaking waves. *J. Phys. Oceanogr.*, **30**, 2404-2418.
8. M. Onorato, M., A.R. Osborne, and M. Serio, 2002: Extreme wave events in directional, random oceanic sea states. *Phys. Fluids*, **14**, 25-28.
9. M. Onorato, M., A.R Osborne, and M. Serio, 2006: Modulational instability in crossing sea states: A possible mechanism for the formation of freak waves. *Phys. Rev. Lett.*, **96**(1), 014503.
10. M. Onorato, L. Cavaleri, S. Fouques, O. Gramstad, P.A.E.M. Janssen, J. Monbaliu, A.R. Osborne, C. Pakozdi, M. Serio, C.T. Stansberg, A. Toffoli, and K. Trulsen, 2008: Statistical properties of mechanically generated surface gravity waves: a laboratory experiment in a 3D wave basin. *J. Fluid Mech.*, submitted.
11. T. Waseda, T., and M.P. Tulin, 1999: Experimental study of the stability of deep-water wave trains including wind effects, *J. Fluid Mech.*, **401**, 55-84.
12. T. Waseda, T., T. Kinoshita, and H. Tamura, 2008, Evolution of a random directional wave and freak wave occurrence. *J. Phys. Oceanogr.*, submitted
13. I.R. Young, A.V. Babanin, 2006, Spectral distribution of energy dissipation of wind-generated waves dominant wave breaking, *J. Phys. Oceanogr.*, **36**(3), 376-394.