INFLUENCE OF ARTIFICIALLY GENERATED AIR BUBBLES ON A WAVE BREAKING

D Merkoune, A Ezersky, N Abcha, F Amine, and D Mouazé
Laboratoire de Morphodynamique Continentale et Côtière UMR 6143 CNRS
Université de Caen, F-14000 Caen, France

E-mail: djalal.merkoune@unicaen.fr

Abstract. We report experimental results on influence of air bubbles curtain on wave breaking. It was found that position of wave breaking point depends on bubble concentration in water. It was revealed that the effect of wave breaking is very sensitive to the concentration of air bubbles which are situated near free surface of water. We showed that small concentration of artificially created bubbles do not lead to additional dissipation of energy in surface waves but change sufficiently the position of breaking point. This phenomenon could synchronize the breaking of irregular surface waves in the ocean and lead to the generation of spatially inhomogeneous turbulence in the upper layer of the ocean.

1. Introduction

Breaking of water waves plays an important factor in many ocean studies, such as air-sea interaction, remote sensing, wave dynamics, and gas transfer to the atmosphere. Wave breaking is accompanied by the appearance of turbulent zones and clouds of air bubbles. Many studies have been made on characteristics of turbulence and bubbles generated by breaking wave. For example size distributions of bubbles have been studied in details for natural conditions [1] and in numerical simulations [2]. On the other hand the process of calming wave by injecting air bubbles beneath the water surface has been discussed for century (see [3] and papers cited there). It was found that intense curtain of air bubbles can sufficiently reduce amplitude of surface wave. In the presented paper we concentrate our attention on the following problem: how air bubbles influence on wave breaking.

2. Experimental setup

Experiments were carried out in a channel of $L=22$ m length, $D=0.8$ m width; water depth was $H=0.5$ m. At one end of the channel wave maker was situated, at the other end a porous beach was installed to minimize wave reflection. (See Fig. 1). We used computer controlled wave maker to generate periodically propagating wave trains with frequency modulation. Initial duration of wave train was approximately 12 seconds and period of repetition was close to 30 seconds. The modulation frequency of wave train results in dispersion focusing of surface waves. Decreasing of impulse duration and increasing of its amplitude along the channel is shown in Fig.2. Such a process called

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1 To whom any correspondence should be addressed.
“Dispersion focusing” led to the wave breaking at a definite distance from the wave maker. Position of wave breaking was defined by the amplitude of wave train and index of frequency modulation. In our experiments the length of focus was approximately 14.5 m. We studied the influence of artificially created bubbles on dynamics of surface waves. The bubble curtain was generated in the position of channel where amplitude of wave train did not reach yet critical value corresponding to wave breaking. For this purpose we placed on the bottom of channel cylindrical tube connected with air compressor. Axis of tube was perpendicular to the lateral wall. Small holes of the same diameter were drilled periodically in the wall of the tube to generate air bubbles. We investigated the evolution of free surface displacement of nonlinear wave for different values of air flux and, consequently, for different concentrations of air bubbles in curtain.

![Figure 1. Experimental setup: T1, T2, T3 are resistive transducers for free surface measurement, PB is porous beach.](image1)

### Figure 1.

![Figure 2. Evolution of wave packet along the channel. Time series recorded by three transducers for a pulse with averaged frequency f=0.75 Hz.](image2)

![Figure 2.](image2)

3. Results and discussion

The wave profile was recorded by means of the high-speed video camera. We processed frame by frame image analysis gives of the quantitative information on characteristics of a free surface near point of wave breaking. Horizontal coordinate corresponding to the vertical tangent of free surface of water was considered as a point of wave breaking. We studied the influence of air bubbles on process...
of wave breaking process for two type of experiments. In the first type of experiments bubbles were generated by air compressor continuously. In this case we revealed that position of the of wave breaking point essentially depends on air flux, and even small concentration of artificially generated bubbles led to the displacement of wave breaking point in the direction to the wave maker. A change in position of wave breaking point is shown in fig. 3. The most large influence of bubbles is observed for air flux increasing from zero to $0.2 \times 10^{-3}$ m$^3$/s. Breaking point displacement attains 40 cm. Further increasing of air flux leads to the slight changing in wave breaking position point.

In the second type of experiments we investigated wave breaking after stopping artificial wave aeration. Experiments were organized as follows: generation of bubbles occurred during several minutes, thereafter air compressor was stopped. During several minutes air bubbles were rising to the water surface and influence of water aeration on wave breaking was observed in experiment. Dependence of displacement of a wave breaking point on time after stoppage of water aeration by compressor is shown on fig. 4. It should be noted that in our experimental condition the influence aeration preserves during approximately 5 minutes.

![Figure 3. Dependence of wave breaking coordinate $x$ on value of air flux $Q$. In the absence of air curtain wave breaking occurs at coordinate $x=50$ cm.](image3)

![Figure 4. Dependence of wave breaking coordinates on time. At $t=0$ air compressor was stopped. Points correspond to seven different series of experiments. Solid line was obtained by averaging over all data. In the absence of artificial aeration of water wave breaking occurs at coordinate $x=40$ cm.](image4)

To investigate the influence of bubbles on wave breaking more precisely we studied changes of wave train energy for different air flux. Under the energy of wave train we mean the following expression: $E = \frac{g D}{2} \int v_s(\omega) |S(\omega)|^2 d\omega$, $g$ is for acceleration of gravity, $v_s$ is group velocity, $S(\omega)$ is Fourier spectrum of surface wave elevation $\eta$. Our calculations showed us that this integral practically coincide with the following expression: $E = \frac{g D}{2} v_s \int_0^T \eta^2 dt$, $v_s$ is group velocity of spectral maximum, $T$ is duration of wave train. We examined energy of time series obtained by resistive transducers T1, T2, T3 in different points along the channel as a function air flux $Q$. Results are
presented in Fig. 5. Bubble curtain does not influence on wave train energy before the wave breaking point, there exist small decreasing of the energy due to viscous dissipation (curves T1 and T2, Fig. 5). Wave train energy after wave breaking point slightly depends on air flux $Q$ (curve T3). Our experiments have demonstrated that supplementary energy dissipation introduced by artificially created air bubbles is very low in comparison with energy dissipation due to wave breaking. essentially influence the dynamics of surface waves near the wave breaking point.

![Figure 5. Energy dissipation in the presence of the curtain air bubbles artificial at different locations of the channel.](image)

4. Conclusion:

We have demonstrated experimentally that artificially created air bubble curtain can accelerate wave breaking. According our results such effect is observed for air bubbles concentration which introduces very small energy dissipation in comparison with energy dissipation due to wave breaking. In our opinion this phenomenon could be very important for understanding of spatial inhomogeneous of turbulence. Suppose, for example, that after the breaking of the first wave a cloud of air bubbles appears. Air bubbles could accelerate the breaking of the next wave and lead to the further increasing of bubble concentration. It influences the breaking of the next waves and etc. Finally local zones with high concentration of bubbles and intensive turbulence could appear in the upper layer of the ocean.

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