Chapter 6

Energy dissipation due to wave breaking

6.1 Introduction

Despite great efforts, present knowledge of breaking wave statistics and the related energy dissipation is fragmentary. Our ability to quantify wave breaking processes is inhibited by the absence of good quantitative measures of the distribution of breaking. Numerical models developed during the last 30 years on wind wave mechanics have been based on the transport or spectral balance equation incorporating three dynamical processes: energy input from the wind, wave–wave interactions and dissipation by wave breaking. The first two are distinct dynamical processes that have attracted considerable theoretical, experimental and observational attention, and they are considered in principal calculable. In contrast, dissipation still remains a problem. In his pioneering work, Hasselmann (1974) proposed a dissipation source function that incorporated only some general physical constraints together with many empirical data modified over the years. He argued that although wave breaking is locally a highly nonlinear process, it is in general weak in mean and the spectral dissipation should be a quasi-linear function of $S(\omega)$ with a damping coefficient proportional to the square of the frequency $\omega$. Another approach taken by Kitaigorodskii (1983, 1992), Zakharov and Zaslavskii (1982, 1983) and others, was based on the weak turbulence theory of wind waves. It was assumed that energy input from the wind occurs to the largest waves and that dissipation is concentrated at the smallest scales. This theory provides spectral shapes close to those observed, except for shapes over frequencies that are large compared with those of the spectral peak. Komen et al. (1984) revised the Hasselmann solution and developed an expression for the damping coefficient by numerical simulations on the form of this coefficient to reproduce the characteristics of the Pierson–Moskowitz spectrum in the high frequency range.

Phillips (1985) proposed the equilibrium range theory for wind-generated gravity waves in which all three processes are comparable. Under steady wind
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conditions, a quasi-equilibrium develops at high frequencies. The net energy supplied by the other processes determines the number density and distribution characteristics of the breaking events. Phillips based his theory on Toba’s spectrum form \( S(\omega) \approx u_* g \omega^{-4} \) and rates of momentum and energy loss from the wave field by breaking. The resulting amount of energy lost was found to be proportional to the integral of the function \( \approx \omega^{11} S^3(\omega) \) over the high frequency range.

The physical arguments suggest that the loss of energy during breaking should be equal to the difference between the square of the current wave amplitude and square of the limiting wave amplitude which corresponds to the stable condition after breaking. This rationale is behind the Longuet–Higgins (1969) solution for the energy loss during wave breaking for a very narrow frequency spectrum. In Section 6.3 this approach was extended to the two-dimensional probability density function \( f(A, \omega) \).

### 6.2 Experiments on the rates of energy dissipation in breaking waves

The experiments on wave breaking reported in Chapter 4 provide several estimates of rates of energy dissipation due to breaking. In particular, Bonmarin (1989) in his measurements of breaking shows the wavelength decreasing by approximately 20%, the wave height decreasing by approximately 50%, and the steepness of the forward face of the wave decreasing by approximately 75% during breaking. Rapp and Melville (1990) concluded that more than 90% of the total energy lost from the wave field is dissipated within four wave periods after the inception of breaking, and the active breaking itself lasted for a time comparable to the wave period.

Here we give some additional experimental data on the rate of energy dissipation in breaking waves obtained from a different perspective. Thus, let us consider a section of length \( L \) of the crest of one wave. The rate of energy loss associated with this section of the simplified two-dimensional wave field is \( E L N_{br} \), where \( N_{br} \) is the number of breaking waves per wave given by (4.7). If \( L_0 \) is the wavelength of the dominant wave, the rate of energy loss per unit surface area becomes (Thorpe, 1993)

\[
E_{\text{diss rate}} = \frac{E L N_{br}}{LL_0} = \frac{E N_{br}}{L_0} = (1.9 \pm 1.1) \times 10^{-4} \rho_w \left( \frac{V_{10}}{C_0} \right)^3 \frac{C_{br}^5}{gL_0}
\]

or

\[
E_{\text{diss rate}} = (3.0 \pm 1.8) \times 10^{-5} \rho_w \left( \frac{C_{br}}{C_0} \right)^5 V_{10}^3 \quad [\text{J/m}^2\text{s}],
\]

in which \( C_{br} \) is the phase speed of the breaking waves measured relative to the underlying flow. The characteristic phase speed of the breaking waves \( C_{br} \) has been estimated in a few laboratory experiments. Oakey and Elliot (1982)