PART I

Characteristics of Coastal Waves and Currents

San Maria di Leuca

CHAPTER 1

BREAKING WAVES PROPAGATING OVER A SHOAL

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Abstract

Spectral evolution of breaking and nearly breaking waves propagating over a submerged trapezoidal bar has been investigated in laboratory experiments. It is found that wave breaking itself does not play a crucial role in the evolution of the spectral shape, but contributes simply by extracting energy roughly in proportion to the local spectral density. For nonbreaking waves, a Boussinesq model with improved dispersion characteristics is found to simulate the wave evolution very well. On the basis of these findings, it is suggested to combine a semi-empirical model for the overall energy dissipation with a nondissipative Boussinesq model so as to obtain a model for simulation of spectral evolution of breaking waves.

1. Introduction

Harmonic generation in waves passing over submerged obstacles has long been known experimentally (Johnson et al., 1951; Jolas, 1960; Byrne, 1969; Young, 1989). On the theoretical side, Phillips (1960), Bretherton (1964), Mei and Unlüatta (1972) and Bryant (1973), among others, clarified the basic mechanisms of harmonic generation.

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While for nonbreaking waves the generation of high-frequency energy may entirely be attributed to conservative nonlinear effects, the role of wave breaking in this process has not been clarified. The aim of the work reported here is to help resolve this question and to contribute to the development of capabilities for numerical modelling of the dominant processes involved.

A full account of the work reported here can be found in Beji and Battjes (1992a, 1992b) for the experimental and the numerical aspects, respectively.

2. Experiments

The experiments were carried out in a wave flume of the Department of Civil Engineering, Delft University of Technology. The flume is 37.7 m long and 0.8 m wide. In its midsection, a trapezoidal bar was built. See Figure 1. At the downwave end a gently sloping spending beach was present from previous experiments. The still-water depth was 0.4 m over the original, horizontal flume bottom and had a minimum of 0.10 m above the bar crest. Periodic and irregular input waves were used, the latter with a JONSWAP-type spectrum and a very narrow band spectrum. Peak frequencies were f_p=0.4 Hz, f_p=0.5 Hz and f_p=1.0 Hz. Measurements of the free surface elevations were made with parallel-wire resistance gages at eight different locations as sketched in Figure 1.

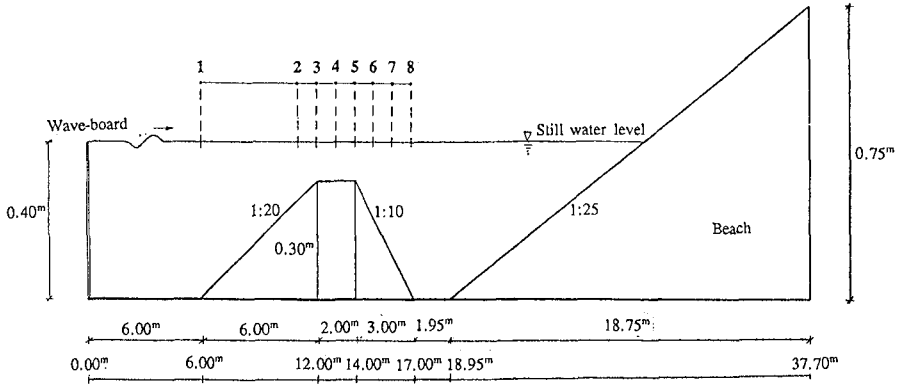

Figure 1. Longitudinal sections of wave flume

3. Experimental Results

Experiments with three different wave conditions were done: steep but non-breaking waves, spilling breakers and plunging breakers.

In order to make direct comparisons of spectral evolutions for different wave conditions, spectral estimates obtained at stations 2, 4, 6, and 8 for JONSWAP type incident waves (f_p=0.4 Hz), for non-breaking and plunging breakers, are normalized and plotted together. The normalization is such that the total area under the spectrum for every case is unity. Figure 2 shows these comparisons. Obviously, the spatial evolution of the spectral shape follows almost identically the same trend regardless of the occurrence of wave breaking. The same was observed in the case of narrow-banded incident waves with the same peak frequency (not shown here).

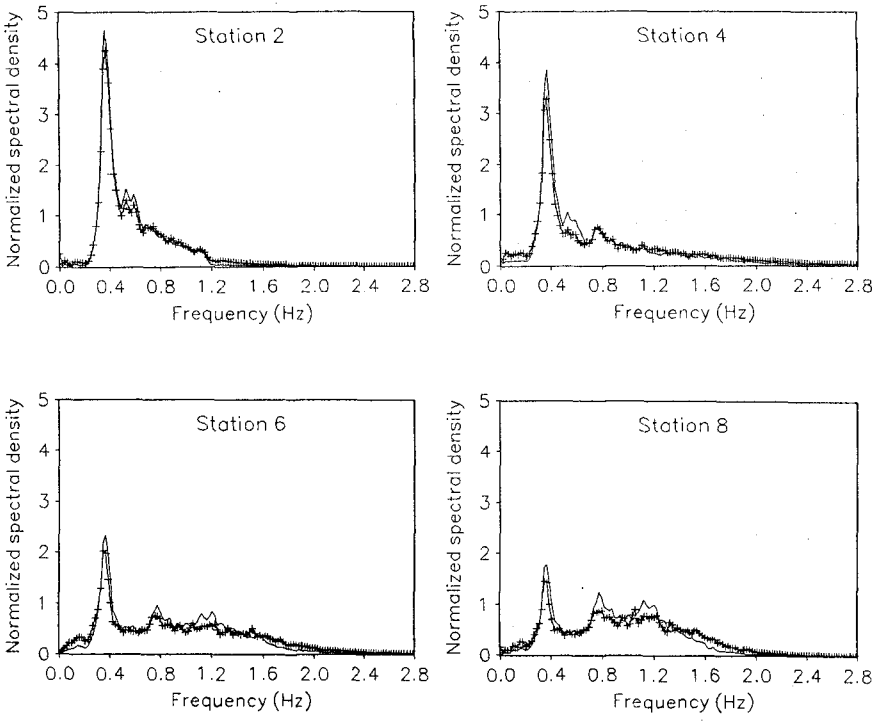

Figure 2. Normalized spectra at different stations; —: Non-breaking waves; +++: Plunging breakers. Incident waves: Jonswap-spectrum with f_p=0.4 Hz.

The measurements with the short waves (f_p=1.0 Hz) revealed little spectral shape evolution over the obstacle. See Figure 3. The shape of the input spectrum in every case remained nearly intact over the entire region and only a relatively small amount of high frequency energy was generated. For this reason we shall not pursue this case any further.

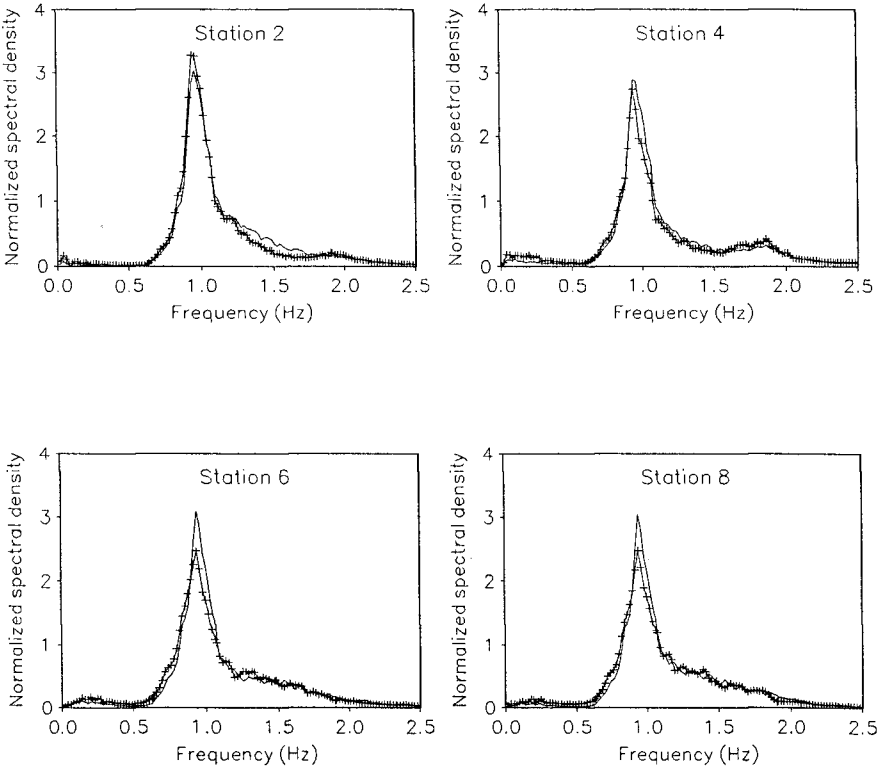

Figure 3. Normalized spectra at different stations; —: Non-breaking waves; +++: Plunging breakers. Incident waves: Jonswap-spectrum with f_p=1.0 Hz.

4. Numerical modeling

4.1 Nonbreaking waves

A Boussinesq type model with improved dispersion characteristics was chosen as the wave propagation model. We used it in the following form:

$$u_t + uu_x + g\zeta_x = \frac{1}{3}h^2 u_{xxt} + hh_x u_{xt} + bh^2 (u_t + g\zeta_x)_{xx}$$

$$\zeta_t + [(h+\zeta)u]_x = 0$$

where ζ denotes the surface displacement and u the vertically averaged horizontal velocity. For b=0 the momentum equation reduces to its standard form as it was derived by Peregrine (1967) for mildly sloping bottoms. For b=1/15 a major improvement for the dispersion characteristics is achieved. This extension to the original Boussinesq equations was first suggested by Witting (1984) and further elaborated by Madsen et al. (1991). A model with good dispersion characteristics is essential in this study because of the decomposition of the wavefield behind the submerged obstacle into free high frequency components which may be regarded as relatively deep water waves.

In the numerical treatment of the governing equations, we basically followed the guidelines given in Peregrine (1967), except for some minor but crucial adjustments.

In Figure 4, the left column gives measured and computed free surface elevations for nonbreaking but significantly nonlinear random waves at selected stations. The right column shows the comparisons for the measured and computed spectra at the same stations. The agreement is remarkable and justifies our choice of the governing equations.

4.2 Breaking waves

The observation that in our experiments the evolution of the spectral shape is not significantly affected by wave breaking suggests the possibility of using a (non-spectral) model for the dissipation of total wave energy by breaking (e.g., Battjes and Janssen, 1978), in conjunction with a conservative (potential-flow) model incorporating nonlinear wave-wave interactions.

Results of a fully integrated model of the kind indicated here are not yet available. Nevertheless, to indicate the potential feasibility of this approach we show results for the plunging breaker case (JONSWAP spectrum, f_p = 0.4 Hz) for which the initial surface elevations are reduced (in the calculations) with a factor 1.5 so as to ensure

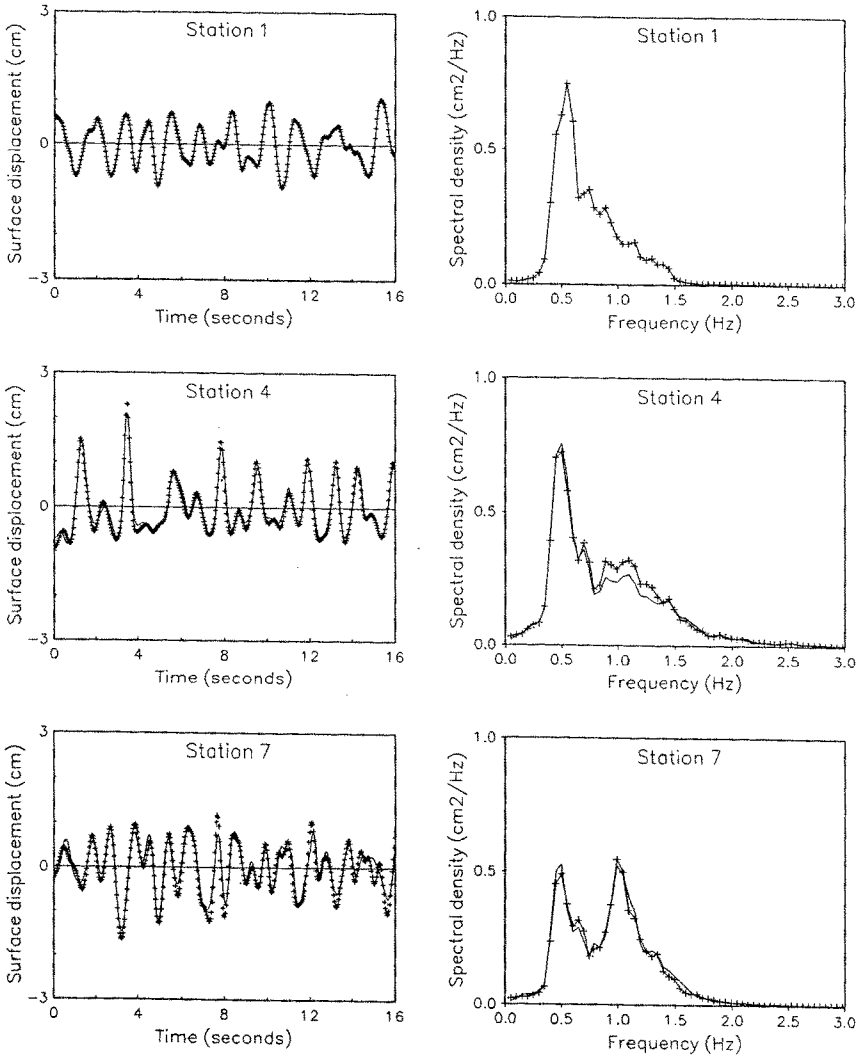

Figure 4. Comparisons of measured (—) and computed (+++) surface elevations (Left) and spectra (Right) at different stations. Incident waves: Jonswap-spectrum with f_p=0.5 Hz; No breaking.

non-diverging calculations, as in the case of the steep but non-breaking waves simulated at full strength. The idea behind this is that the strength of the nonlinearities in post-breaking waves is expected to be comparable to that in non-breaking waves of similar height.

Figure 5 compares the evolutions of the measured spectral shape for plunging breakers with those of the computations carried out with the down-scaled amplitudes. All the spectra shown have been normalized, as in Figure 2, so that their integral is unity. (Minor differences between the measured spectra in the two figures are due to the fact that the spectra in Figure 5 were calculated from a partly different set of time series, and with a coarser frequency resolution, than those shown in Figure 2.) It can be seen in Figure 5 that the spectrum, computed on the basis of an artificially reduced initial wave height, evolves in a similar manner as the observed spectrum does for the breaking waves.

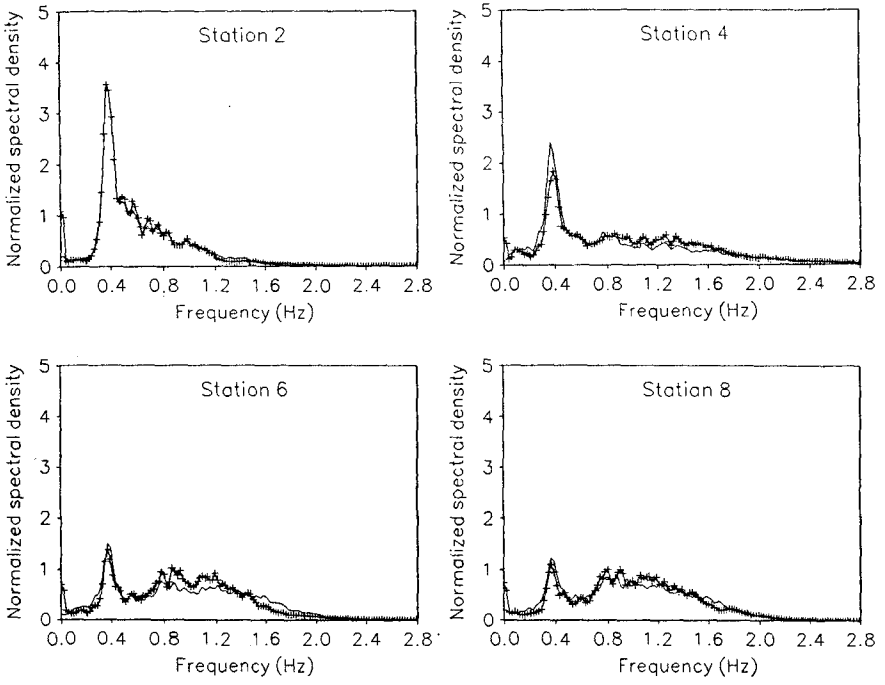

Figure 5. Comparison of measured (—) normalized spectra for plunging waves and normalized spectra computed with reduced initial values of surface elevations (+++). Incident waves: Jonswap-spectrum with f_p=0.4 Hz.

This is taken as an indication that it is worthwhile to develop the combined modeling approach sketched above.

5. Conclusions

Energy spectra obtained from laboratory measurements are analyzed to clarify the effects of wave breaking on the inherently nonlinear phenomenon of high frequency energy generation and transfer in the spectra of waves traveling over submerged profiles. For the conditions in these experiments, it is found that wave breaking merely dissipates energy in averaged manner and does not introduce drastic alterations to the spectral shape.

A practical application of this finding is the possibility of combining a weakly nonlinear non-dissipative model with a semi-empirical dissipation formulation for the total energy.

Acknowledgements

Financial support for this project was provided in part by the EC-MAST program within the framework of the WASP-project under contract number MAST-0026-C(MB).

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