Efficient Simulation of Extreme Waves in a Random Sea

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INTRODUCTION

This presentation will summarize an efficient procedure for generating a rogue or freak wave within a random sea in a laboratory wave tank. This procedure was originally presented at ISOPE 2000. Work is now in progress to investigate the dynamic response of fixed structures to these extreme waves.

BACKGROUND

This work adopts a simple definition of a rogue or freak wave as an individual wave whose height exceeds two times the significant height, i.e. $H>2H_S$, or as a wave whose crest amplitude is more than 1.1 times the significant wave height.

In traditional wave tank tests, it is rare to achieve an individual wave satisfying either of the above criteria. If waves are simulated from a wave spectrum using random phasing of the spectral wave components, Rayleigh statistics suggest that $H > 2H_S$ will occur only once in about 3,000 waves. This method, illustrated in Figure 1A, is therefore not very efficient for simulating freak waves.

An alternative approach uses transient waves, where the phases of the spectral wave components are selected so that waves converge into a narrow wave group. This approach is also problematic, however, in that the water surface both prior to and following the extreme wave is essentially quiescent which is unrealistic. This is illustrated in Figure 1B, where a transient wave is generated from the same wave spectrum as that used in Figure 1A.

In the present study, we introduce a more efficient and realistic way of simulating extreme waves, by simply combining these two methods. Figure 1C shows a typical result in which an extreme transient wave has been embedded into a random sea to produce a realistic extreme-wave sea-state.

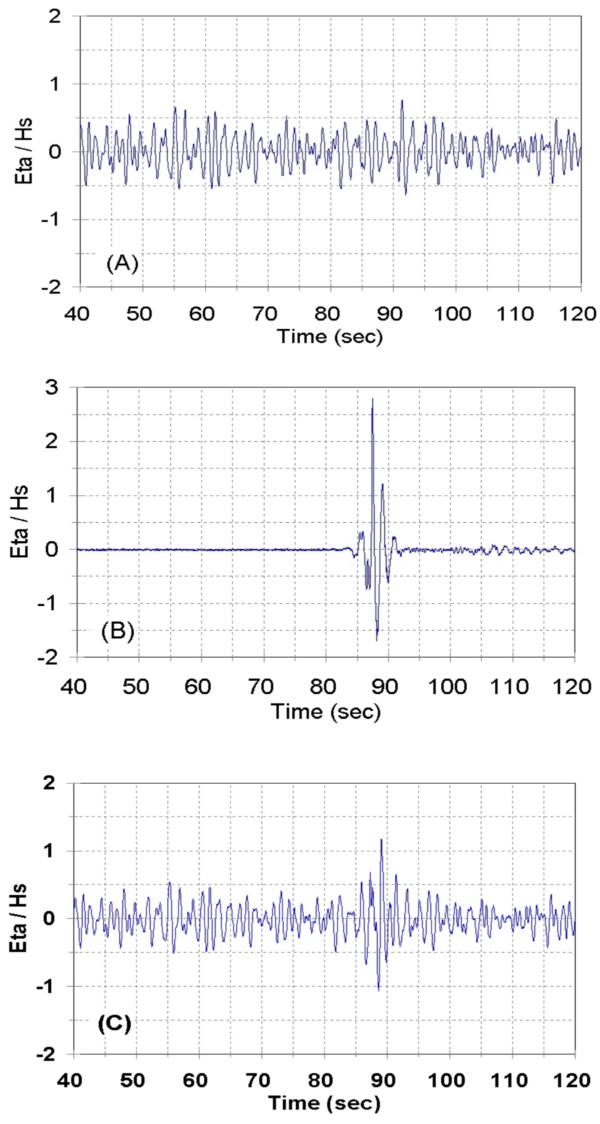

Figure 1. Sample wave records generated from the same spectrum using (a) random phases, (b) contrived phases to produce a transient wave, and (c) both contrived and random phases (20% of the energy into the transient wave and 80% into the random sea)

WAVE GENERATION PROCEDURE

In this study, we embed an extreme transient wave within a random sea, based on a partitioning of the total spectral wave energy: with one part of the energy going into to the underlying random sea, and another part going into the focused transient wave.

To illustrate, imagine a wave spectrum, and then split the wave energy at each frequency so that some percentage, P_R, is used to generate the random sea and the other part, P_T, is used to generate the transient wave (thus $P_R + P_T = 1$).

Once these percentages are selected, the water surface is obtained by summing a random wave time series, generated using random phases, N_n, and a transient wave time series, generated using specified phases, as

$$\eta(x,t) = \sum_{n=1}^{n=N} A_{Rn} \cos(k_n x - \sigma_n t + \phi_n) + \sum_{n=1}^{n=N} A_{Tn} \cos(k_n (x - x_C) - \sigma_n (t - t_C))$$

where each wave component, *n =1, 2,...,* has wavenumber k_n and frequency Φ_n. The amplitudes of the random and transient parts are then defined from the spectrum, $S(\Phi)$, according to the specified division of energy as

$$A_{Rn} = \sqrt{2\, P_R\, S(\sigma_n)\, \Delta\sigma}$$

$$A_n = \sqrt{2\, P_T\, S(\sigma_n)\, \Delta\sigma}$$

The remaining parameters, x_C and t_C, represent the distance and time at which the transient waves will converge.

EXPERIMENTAL RESULTS

Experiments were conducted in which the percentages of energy in random and transient waves, P_R and P_T, were varied over a full range of 100% to 0%. Tests were conducted in the U. S. Naval Academy in a wave tank 37 m long and 1.5 m deep. Waves were generated from a wave spectrum with 240 frequency components extending from 0 to 2 Hz.

Each time series was only 120 seconds long. The transient wave components were set to converge at a distance from the wavemaker of x_c = 15.2 m at a time of 89 sec into the run.

Figure1c shows the resulting time series for a case where 80% of the energy went into the random sea while just 20% went into the transient wave. This condition produced a realistic sea containing a large wave having *H* = 2.24 *Hs* and *A* =1.18 *Hs,* satisfying the adopted definitions of freak waves. Other tests produced similar results with as little as 15% of the energy in the transient wave.

One other interesting and useful result of this procedure is that the sea state retains realistic statistical properties. The resulting sea state has water surface elevations that appear to follow the Gaussian distribution and has wave heights that follow Rayleigh distribution, with the exception of a large outlier rogue wave, as shown in Figure 2.

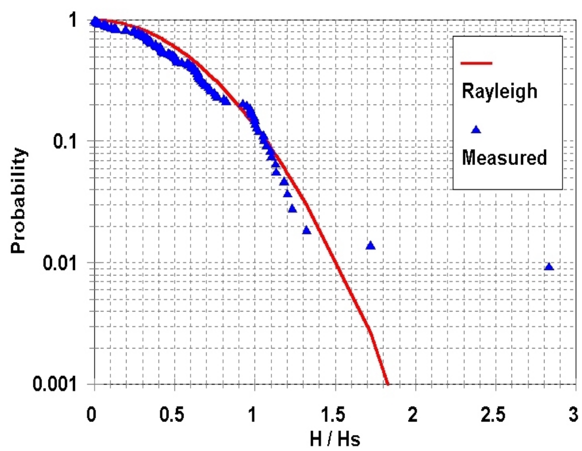

Figure 2. Wave heights compared to the Rayleigh distribution for time series in Figure 1c.