Proceedings of the Eighth (1998) International Offshore and Polar Engineering Conference
Montréal, Canada, May 24-29, 1998

ISBN 1-880653-34-6 (Set); ISBN 1-880653-37-0 (Vol. III)

Wavelet-Based Bicoherence Analysis of Irregular Wave Data

E.J. Powers, E.-J. Yi, I.-S. Park and J.-H. Chung
University of Texas at Austin
Austin, TX, USA

Abstract

In this paper wavelet-based bicoherence spectra are utilized to detect short-time duration phase coupling associated with short-lived, yet "strong", nonlinear interactions between first-order and second-order wave components. Such strong, but short-lived, interactions have been previously shown to be associated with large-amplitude extreme-like waves. Confirmation of the wavelet-based bicoherence results is provided by the decomposition of the experimentally observed wave elevation into its first- and second-order components. This is accomplished with the aid of a second-order Volterra digital filter. The efficacy of the approach is demonstrated using model basin irregular wave data.

Key Words : Wavelets, bicoherence, irregular waves.

I. Introduction

Power spectral analysis, based on Fourier analysis, has proven to be a common and powerful tool with which to characterize wave elevation time series. This is evidenced by a number of standard spectra such as JONSWAP and Pierson-Moskowitz spectra [1]. However, power spectra contain no information on phase and, thus, are of little or no use when considering nonlinear wave interactions which are characterized by phase coupling (or phase coherence) between the interacting frequency (and wavenumber) components. In the case of quadratic, or three-wave interactions, the bispectrum, or its normalized form the bicoherence, has proven to be a powerful tool with which to detect quadratic phase coupling associated with three-wave nonlinear wave interactions [2]. Since classical power spectral analysis and bispectral analysis are based on the Fourier transform, no temporal resolution is provided. In this paper we are concerned with analyzing irregular wave elevation time series data where we wish to consider nonlinear interactions between first and second-order wave components as a function of time. Clearly, Fourier-based bispectral analysis is not adequate to meet the goals of this study.

In [3] a time-domain second-order Volterra digital filter was utilized to decompose an experimentally generated irregular wave-elevation time series into its first- and second-order components. Furthermore, it was shown that the occurrence of very large-amplitude extreme-like waves was associated with a strong (compared to the remainder of the time series) short-time duration phase locking (or phase coupling) between first- and second-order components. Moreover, these experimental results were in good agreement with the analytical and numerical work of Stansberg [4]. Since the high-degree of phase coupling occurs over a relatively short period of time, clearly Fourier-based bispectral analysis is not suitable to detect it.

In recent years the wavelet transform [5] has proven useful in studies where it is desirable to characterize both time and frequency (actually scale, to be defined later) characteristics of a signal. For example, wavelet transforms have proven powerful in detecting and localizing (in time) transient events in electric power systems [6]. This raises the question as to whether a wavelet-based bispectrum may prove useful in detecting the high degree of short-term phase coupling associated with the occurrence of very large-amplitude extreme-like waves. Wavelet based bispectra have been used in studies of plasma turbulence [7], and we have presented some very preliminary results on wavelet-based bispectral analysis in [8]. The objective of this paper is to present a more detailed study of the ability of wavelet-based bispectra to detect short-term phase coupling associated with very large amplitude extreme-like waves.

In Sec. II we review the continuous wavelet transform and the Morlet wavelet used in this study. Fourier-based and wavelet-based bispectra and bicoherence spectra are presented in Sec. III. The experimental time series data used in this paper were collected at the Offshore Technology Research Center Model Basin and correspond to a 100-year Gulf of Mexico storm. Experimental details are provided in Sec. IV. In Sec. V we utilize a second-order Volterra digital filter to decompose the experimentally observed wave time series data into first- and second-order components. On the basis of examining the first- and second-order time traces (shown in Sec. VI), one can observe (qualitatively) that the degree of quadratic phase coupling is not constant in time. For example, a very strong degree of phase coupling is evident in the vicinity of an extreme-like wave, while over much of the wavetrain the phase coupling is much weaker. In Sec. VI, we use a wavelet-based bicoherence to analyze the wave elevation time series. In this study our temporal resolution is 15 times better than in our preliminary study [8]. To illustrate the efficacy of the wavelet-based bicoherence, we consider two brief time segments, one characterized by a high degree of phase coupling of first- and second-order compo-