International Journal of Offshore and Polar Engineering
Vol. 7, No. 3, September1997 (ISSN 1053-5381)

Numerical Simulation and Spectral Analysis of Irregular Sea Waves

Celso K. Morooka and Irineu H. Yokoo
State University of Campinas, Campinas, São Paulo, Brazil

ABSTRACT

The most used methods of numerical simulation of linear irregular sea waves are studied, including the Wave Superposition Method and inversions of FFTs. An alternative method applying Walsh functions is also used. The generated wave records are analyzed applying the well-known FFT Method and the Maximum Entropy Method. Results of the simulations are presented for the Deterministic (DSA) and the Nondeterministic (NSA) models. The results of the simulations are compared from the point of view of computational efficiency, estimated spectra and statistical properties of the generated records. Finally, the wave records are used in the motion analyses of a semisubmersible platform in time domain.

INTRODUCTION

In the study of the dynamic behavior of floating structures in irregular waves, two steps are of great importance: the digital simulations of the sea surface elevations, and the spectral analyses of the generated sea waves time series. And recently great effort has been spent to successfully represent ocean waves through computational programs, and several methods of spectral analysis and statistical calculations have been developed to analyze the wave records. In the present work, some of these methods of wave simulation and spectral analysis are shown and applied in the study of the motions of floating structures.

Sea waves are of stochastic nature and, mathematically, are represented as Gaussian stationary and ergodic processes. The models used to represent these processes are based on the work of Rice (1944, 1945), who presented two formulations (Deterministic Spectral Amplitude and Nondeterministic Spectral Amplitude) to represent electronic signals as Gaussian stationary processes from previously specified energy spectra. These methods are largely used in the simulation of irregular sea waves and are known as the Wave Superposition or the Summation models; they were applied by Morooka and Yokoo (1992) for the simulations of directional waves. Borgman (1969) applied these models and introduced the simulation through white noise filtering in time domain. Shinozuka (1971) has shown a method to simulate a class of multivariate and multidimensional random processes with specified cross-spectral densities. Later, Wittig and Sinha (1975) presented a method of synthesis of random processes using Fast Fourier Transforms (FFTs) of the spectrum in frequency domain. This method was improved by Hudspeth and Borgman (1979) with the application of FFT routines for real numbers.

Simulated or measured time domain wave records can be used for the estimation of wave spectra. There are several methods for spectral estimation; the most used are the Traditional Methods based on Fourier transforms of the signals in time domain. The Parametric Methods are another well-known family of methods that include the AR, MA and ARMA. Other methods used in signal processing are the Maximum Likelihood Method (MLM) and the Maximum Entropy Method (MEM). For Gaussian stochastic processes the MEM is equivalent to the AR.

In this work, the Wave Superposition and FFT methods are applied for the simulation of irregular wave records. An alternative technique applying Walsh functions is used similarly to the Superposition Method. The wave records are analyzed through the Direct Method, which is the most common Traditional Method, and through the MEM. The main statistical properties are calculated from the wave records.

WAVE SUPERPOSITION METHOD

Ocean waves are treated as zero mean stationary Gaussian processes, represented in frequency domain by energy spectra. Rice (1944, 1945) presented mathematical models to represent electronic noise of Gaussian distribution with zero mean and variance determined from the white noise spectrum filtered by a specified spectrum. Later these models were applied to sea waves simulations, being known as the Wave Superposition Method or the Summation Method.

The first method suggested by Rice represents the sea surface elevation ($\eta(t)$) as a discrete Fourier series:

$$\eta(t) = \sum_{n=1}^{N}(a_n \cos\omega_n t + b_n \sin\omega_n t) \qquad (1)$$

where a_n and b_n = independent random variables that are distributed normally around zero with the standard deviation = $\sigma_n = \sqrt{S(\omega_n)\Delta\omega}$; $S(\omega)$ = specified wave spectrum; and $\omega = 2\pi f$ = frequency ($f > 0$).

The Fourier coefficients are calculated by filtering the white noise spectrum with the specified one. As the white noise spectrum is unitary, the filtered spectrum is equal to the specified spectrum. The coefficients a_n and b_n are random variables, so Eq. 1 is called Nondeterministic Spectral Amplitude (NSA). The second model for Gaussian signals introduced by Rice is represented by:

$$\eta(t) = \sum_{n=1}^{N} A_n \cos(\omega_n t - \varepsilon_n) \qquad (2)$$

where $A_n = \sqrt{2S(\omega_n)\Delta\omega}$; and ε = phase angle distributed at random ($0 < \varepsilon < 2\pi$).

Received March 10, 1995: revised manuscript received by the editors April 12, 1997. The original version (prior to the final revised manuscript) was presented at the Fifth International Offshore and Polar Engineering Conference (ISOPE-95), The Hague, The Netherlands, June 11-16, 1995.
KEY WORDS: Sea waves, simulation of irregular waves, wave statistics, floating platform dynamics.