Proceedings of the Eighteenth (2008) International Offshore and Polar Engineering Conference
Vancouver, BC, Canada, July 6-11, 2008

ISBN 978-1-880653-70-8 (Set); ISBN 1-880653-68-0 (Set)

An Integration Procedure to Calculate Response Spectral Moments of Offshore Structures

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ABSTRACT

In this paper, an alternative integration procedure is presented to calculate response spectral moments of offshore structures. The multi-directional sea spectrum is used in the calculation of response spectra so that the integration procedure of spectral moments will be twofold as being a) integration in the wave directional domain and b) integration in the frequency domain. In the wave directional domain, the integration is transformed to the Gaussian type by using a variable transformation. The related orthogonal polynomials are Chebyshev Polinomials of the Second Kind, from which the abscissas and weight factors are calculated from simple trigonometric functions. In the frequency domain, the total integration region is divided into some frequency sub-regions, which are generated on the base of maximum errors between the exact and exponentially simulated functions. Having generated frequency sub-regions, each sub-region is simulated by a fifth order polynomial function. Then, analytical integrations are performed to calculate spectral moments in each sub-region, by which harmonic oscillations are avoided. The total integration is obtained by summing up individual integrations for the sub-regions. The determination of exponential and polynomial simulation functions and the generation of frequency sub-regions are explained. It is demonstrated that the method introduced in the paper is an alternative tool for the numerical integration of response spectra.

KEY WORDS: Offshore structures, Response spectra, Simulation function, Numerical integration, Spectral moments.

INTRODUCTION

In the stochastic analysis of offshore structures, stress statistical quantities, which are required in the probabilistic reliability analysis, are calculated in terms of spectral moments of stresses. Under zero-mean random input-processes, such as sea waves, responses of a linear system that is assumed mostly in the spectral analysis will also be zero-mean random processes. But, response amplitudes, which are important measures of responses, become non-zero-mean processes. Their mean values are used in the structural design under stochastic wave loading. Probability distributions and the mean values of response amplitudes are obtained from statistical response-quantities that are calculated from spectral moments so that they play an important role in the stochastic analysis. Their calculation needs a special attention since a required response measure, which may be used to check a threshold value as one of design criteria, depends on the spectral moments, which are calculated from integrations of response spectra with respect to the frequency and also wave direction if multi-directional sea spectrum is taken into account. There are many books and reports about these subjects, see e.g. Barltrop and Adams (1991), Brebbia and Walker (1979), Chakrabarti (1987, 1990, 2005), Karadeniz (1979, 1989, 1992). In the probabilistic analysis of offshore structures, the calculation of response spectral moments is required for the extreme value statistics of structural responses. The formulation of response spectral moments has been presented in Karadeniz (1983), assuming that a) water is deep, b) the distributed wave forces are lumped at the member ends by using the consistent-force concept with exact wave load distribution, c) the sea spectrum is known as, for example, Pierson-Moskowitz sea spectrum (Chakrabarti, 1990). A response spectrum is calculated in terms of the sea spectrum and some transfer functions between inputs and outputs. A conceptual formulation of the response spectra is presented herein prior to the main subject of this paper as being preliminary information, which is thought to be useful to understand the essence of the problem.

For deep water condition, the transfer function vector of the distributed wave load for a structural member, Morison's equation (Sarpkaya and Isaacson, 1981), can be stated as

$$\{h_{p\eta}(\omega)\} = \omega\ R\ e^{m(Z-i x)}[T]\{\theta\}$$
$$R = \left(C_D A_d + i\,\omega C_M\right) \quad \text{and} \quad \{\theta\}^T = \left(\cos\phi,\ \sin\phi,\ i\right) \tag{1}$$

where ϕ is an individual wave-direction-angle measured from the horizontal X coordinate ($\phi = \theta_0 + \theta$, where θ_0 is the main wave direction angle and θ is an individual wave direction angle relative to θ_0), Z is the vertical coordinate measured from the still water level (upward +), x is the horizontal coordinate in the wave direction and $i = \sqrt{-1}$. C_D and C_M are drag and inertia force parameters and A_d is the linearization coefficient of the drag force term. The consistent force vector of the member is calculated from,