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Extreme Response and Fatigue Estimates in Directional Seas

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ABSTRACT

This paper introduces wave directionality into a joint environmental contour description that has been used previously in the study of extreme response behavior for uni-directional random seas. A modified cosine power-spreading model that accounts for the frequency dependence of the various waves in the design seastate was utilized. Data from the Gulf of Mexico was used to evaluate the coefficients needed to describe the coupled frequency dependent behavior of the wave spreading exponent and the mean direction of wave travel. To illustrate the methodology the dynamic behavior of a generic steel caisson platform was studied. A finite element model of the platform was subject to a joint environmental description of directional seas. The time domain simulation yielded the stress levels at specified platform elevations. Based upon these numerical predictions, fatigue life estimates were evaluated using a simplified Palmgren-Miner approach. Results for both uni-directional and multi-directional sea simulations were obtained and are compared.

KEY WORDS: Wave spreading, directional spectra, environmental contours, cosine spreading, steel caisson platform, fatigue life, extreme responses.

INTRODUCTION

The importance of directional wave behavior on the design of offshore platforms has not been fully recognized in current design practice, although there has been a considerable amount of research on the subject. The directionality of waves in shallow to intermediate water depths can be the result of the interaction of the waves with the seafloor bathymetry or from the interaction of several storms. In deeper water depths the directional behavior could also be the result of the generation process of the waves, the interactions of storms or the focusing of the wave field by larger objects, like islands. Earlier models of wave directionality viewed the process as separable and were reflected in the range of mathematical models that were proposed, see for example Borgman (1969).

Measurement programs targeting the directionally of ocean waves have increased but a fair amount of uncertainty in describing the process still exists. Many studies have been conducted and a conclusive list is beyond the scope of this paper, and only a few pertinent studies will be mentioned (IAHR 1997). In 1963 Longuet-Higgins, Cartwright, and Smith used directional wave buoys in field studies and later, Borgman (1969) used arrays of wave staffs. A comprehensive investigation using a wide range of commercially available directional wave measurement systems was reported by Allender et al. (1989). The results of their study provided practical information on the accuracy and ability of the various systems to perform in the field. Over the years, field measurements and various observations have lead to a wide variety of surface waves spreading models being proposed. Some of the more familiar models include the modified cosine family, the wrapped-Normal models, the vonMises model and others (Borgman 1969, 1994). The field measurements in the Gulf of Mexico reported by Forristall et al. (1978) and other international studies (Goda 1985) were directed towards the use of frequency dependent cosine wave spreading models. These directional spreading models are typically used in conjunction with linear wave kinematics models, whose shortcomings were discussed by Gudmestad (1993). In his article he presents a comprehensive discussion of the differences between predictions and measured results that are important for design. Offshore platforms designed to sustain wave forces using uni-directional sea models may be significantly over designed, particularly for fatigue life estimates. Moreover, uncertainties associated with understanding the mechanisms and kinematic modeling of directional seas has left engineers reluctant to rigorously address wave directionality in the design process.

In this study a frequency dependent cosine power spreading model for directional seas is used to assess the importance of wave spreading on the extreme response and fatigue life estimates of a shallow water steel caisson platform. Caisson platforms were originally designed for temporary oil and gas production in the Gulf of Mexico, but were found to be adequate for more permanent use provided certain criteria were met (Perryman, Imm, and O'Connor 1991). There are two major types of caisson platforms in use today. The first type is a free standing caisson design. It has a large moment of inertia and is driven directly into the seafloor. The caisson itself then resists surface wave, wind, and current loads by transmitting the loads to the foundation. The second type of caisson platform employs a guying system. This system uses steel wires attached to the caisson just below water level to transmit the load directly to a system of piles driven into the seafloor. Figure 1 provides information on the moment of inertia of various steel caisson platform designs at both the mudline and at the mean water level (MWL), as a function of water depth. A guyed caisson platform designed for used for permanent production is