International Journal of Offshore and Polar Engineering
Vol. 9, No. 1, March 1999 (ISSN 1053-5381)

Universal Linear System Model for Storm Sea Loads on column

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ABSTRACT

A universal linear system model has been proposed for laboratory storm sea loads on a fixed vertical truncated column. Good prediction was obtained with ULSM/L (linear diffraction force) except for higher frequency force components. The present study investigates ULSM/L+Q (linear and quadratic transfer function) and ULSM/L+Q+C (linear, quadratic and cubic transfer function) to improve higher frequency force components. It is found that ULSM/L+Q is the best predictor among the above three. It can predict force to the 4th order. Discussion is given on the discrepancies at the crests and troughs of the most severe wave force, which may be attributed to small wave breaking behind the column.

INTRODUCTION

Storm-sea model testing is one of the absolute tasks for designs of offshore structures, so as to avoid the risks that may arise from designs based on Gaussian seas with other approximations. Laboratory-storm seas (LSS) are significantly non-Gaussian and create remarkably nonlinear horizontal force, especially for the surface-piercing-column-supported structures: semi-submersible, tension leg platform, spar platform and ground base structures. Thus, the accurate prediction of LSS loads on these structures is of great interest to engineers and researchers. The ultimate goal of this study is to develop an advanced model for LSS loads on the above structures and to furnish techniques for economic structure designs.

The universal linear system model (ULSM) was proposed while studying wave loads and impacts on vertical truncated columns (Kim and Zou, 1995; Zou and Kim, 1996; Kim et al., 1997). ULSM must employ an appropriate transfer function (ATF) between the input and output amplitude spectrum. To compute the highly nonlinear horizontal kinematics, a stretching formula is used as an ATF (Kim et al., 1995, 1997). L (LTF) for diffraction force is another example of ATF (Kim and Zou, 1998), with which we can predict the nonlinear loads of single columns 11 m, 18 m and 34 m in diameter in LSS measured at MARINTEK (Stansberg et al., 1995). Good agreement is found in general, but in some cases higher frequency nonlinear force is less adequately predicted.

To improve the higher frequency force components, we propose to add Q or Q+C to L. In the above L, Q and C refer to the linear-, quadratic- and cubic-order transfer function, respectively.

The 2nd-order theory for Q (Molin and Marion, 1986) computes the force of 2nd-order but not the 2nd-order pressure. It computes the 1st-order pressure only on the mean wetted surface.

Faltinsen et al. (1995) and Malenica and Molin (1995) proposed 3rd harmonic diffraction theories for C. FNV assumes a slender column, very small wave amplitude and column radius compared to the wavelength, and the same order magnitudes. It addresses the nonlinearity in the near field and linear long waves in the outer field. MM uses an asymptotic expansion to third-order for radius/wave amplitude of O(1) and assumes the outer field to be Stokes waves. Neither of the above models can compute the pressure distribution above MWL.

In spite of the inability to compute the pressure above MWL, ULSM can predict the resultant instantaneous nonlinear force due to LSS when the wave is weakly nonlinear and nonbreaking during the interaction with the structure. ULSM cannot predict impact because the wave is highly nonlinear and creates wave breaking immediately after impact. Krokstad et al. (1996) investigated application of the FNV model with Q, for large volume body ringing loads, and found a promising result.

CONCEPT OF ULSM

The measured incident wave elevation and force are considered nonlinear input and output of a system. Fourier transform (FT) of the above time histories yields the complex amplitude spectra of the input and output. The complex amplitude spectra represent amplitudes of many sinusoids with experimentally created phase angles. Thus, the system is linear in the frequency domain with the experimental phase angles. If we denote the ratio of the output-to-input amplitude by LTF*, the product of LTF* and the wave amplitude spectrum become the measured force amplitude spectrum. Inverse Fourier transform (IFT) of the above force spectrum reproduces the measured wave force time history in the same sampling interval. LTF* is a linear transfer function, but different from the theoretical L (LTF) for diffraction force.

The above approach of predicting the nonlinear measured force time series seems to be trivial. However, it will be invaluably utilized if we can find the theoretical ATF between the input and output spectrum. Hence, our main effort is to find an ATF that gives LTF* to predict the force time series. L is an ATF (Kim and Zou, 1998); likewise L+Q and L+Q+C can be another ATF. Use of Q and C seems to create a problem in keeping the system linear in the frequency domain. However, this is not true, because the force spectrum due to L+Q or L+Q+C is again the amplitudes of sinusoids at the given input wave frequencies. The universal linear system model means in fact that the input and output of the system are always linear in the frequency domain. The above concept is formulated below.

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Received August 12, 1998: revised manuscript received by the editors November 2, 1998. The original version was submitted directly to the Journal.
KEY WORDS: Universal linear system model, appropriate transfer function, linear, quadratic and cubic transfer function, laboratory storm seas, weakly nonlinear wave, nonlinear wave loads.