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Horizontal Force of Vertical Truncated Column in Stokes 5th-Order Waves

C. H. Kim* and Z. M. Wang
Civil Engineering Department, Texas A & M University, College Station, Texas, USA

ABSTRACT

The horizontal forces of a vertical truncated column fixed in a steep regular laboratory wave and many theoretical Stokes 5th-order waves are analyzed by means of diffraction theory and the universal linear system model. Quasi-linear transfer function LTF*, the ratio of force to wave amplitude at the corresponding frequency between the force and wave amplitude spectrum, is used to represent the nonlinear force in the frequency domain. Findings are: (1) The predicted force due to the equivalent Stokes 5th-order wave agrees with the experiment due to the steep regular laboratory wave; (2) the vertical asymmetry of the force time series is caused partly by nonlinear diffraction and increases with the wave height; (3) LTF* has a trend to deviate upward from the LTF line and increases with the frequency and wave height; (4) LTF* at the fundamental frequencies coincides almost with LTF; and (5) the nonlinear peak force is larger than the linear force amplitude and increases with the wave height.

INTRODUCTION

Many offshore structure designs require model testing in the laboratory-storm-seas (LSS), to avoid risks arising from the Gaussian sea assumption and other approximations. LSS often creates a remarkably nonlinear horizontal force, which produces, for instance, springing and ringing of the tension leg platform and ground base structure. These phenomena occur at the high resonance frequencies due to nonlinear high-frequency force components. It has recently been found that the universal linear system model (ULSM) with a linear plus quadratic transfer function L+Q (LTF + QTF) can predict higher frequency force remarkably well (Kim and Wang, 1999). However, in the above study, it was difficult to find the characteristic behavior of the nonlinear force, because the major laboratory waves investigated were irregular. There were force data due to the steep regular wave similar to a Stokes 5th-order wave. But it was too little for finding the above-mentioned general characteristics. We also were unable to find the reason for the vertical asymmetry of the experimental force time series and the relation between the nonlinear force and wave height. These problems may be investigated by systematically analyzing the ULSM forces due to a series of theoretical Stokes 5th-order waves with different periods and heights.

ULSM designates the nonlinear wave elevation time series as excitation (input) and particle kinematics or wave force as the unknown nonlinear response (output) of a system. FFT of the above input and output gives the complex amplitude spectra, which implies the system is linear in the frequency domain. If an appropriate transfer function (ATF) between the input and output amplitude spectrum can be determined, the output spectrum is obtained by multiplying ATF with the input amplitude spectrum. IFFT of the above force spectrum predicts the force time series. For example, in computing the nonlinear horizontal particle velocity field, a newly developed stretching formula was used as ATF (Kim et al., 1995, 1997). Another example of ATF was L of the horizontal force of column. ULSM with L was applied to predict nonlinear horizontal forces of single columns 11 m, 18 m and 34 m in diameter measured in LSS at MARINTEK (Kim and Zou, 1998). Good agreement was found in general but some higher-frequency nonlinear force was less adequately predicted. To improve the prediction of the higher-frequency force components, we assumed L plus Q as ATF. ULSM/L+Q (Kim and Wang, 1999) indeed improved the prediction. Defining a quasi-linear transfer function LTF* for representing ATF, we found LTF* due to a steep regular laboratory wave had some different tendency from LTF (theoretical solution) in the frequency domain. One of our greatest concerns was whether any general trend for LTF* exists. However, it was difficult to study due to the lack of laboratory data for a series of steep regular wave forces. An alternative would be to use a series of theoretical Stokes 5th-order waves, one of which is equivalent to the steep regular wave #332 of MARINTEK (Stansberg et al., 1995). If the ULSM force due to the equivalent wave agrees with the measured force due to wave #332, the ULSM forces due to the series of Stokes 5th-order waves would give the meaningful data necessary for analysis of general trend of LTF*.

As our method employs the diffraction theory and ULSM, it cannot deal with the viscosity effect, the pressure distribution above MWL and breaking waves immediately after the wave body interaction. As the Reynolds and KC numbers about MWL are in the order of 10^9 and 5 respectively, the loading belongs to the Morison regime and falls in the post-critical zone. Thus, vortex shedding may occur. Therefore, the present method should predict the force approximately.

Research on the nonlinear forces is reviewed. Molin and Marion (1986) computed the 2nd-order force of a vertical cylinder. Kim and Yue (1990) computed a complete set of second-order force. Faltinsen et al. (1995) proposed third harmonic diffraction theories. They assumed a slender column, with both wave amplitude and column radius very small compared to the wavelength, and both magnitudes of the same order. It addresses the nonlinearity in the near field with linear long waves in the outer field. Malenica and Molin (1995) used an asymptotic expansion to a 3rd order for the radius/wave amplitude of O(1) and assumed the outer field to be Stokes waves. These 3rd-order models compute

*ISOPE Member.

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KEY WORDS: Quasi-linear transfer function LTF*, universal linear system model, Stokes 5th-order wave, steep regular laboratory wave, nonlinear wave loads, linear and quadratic transfer function.