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A Universal Linear System Model for Kinematics and Forces Affected by Nonlinear Irregular Waves

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ABSTRACT

A new and unique universal linear system model is proposed for predicting particle kinematics and forces on a structure affected by measured nonlinear irregular waves. The predicted and measured data are in excellent agreement. Application of the model seems to be diverse, and it is envisioned that the technique may be employed for excellent simulation of nonlinear responses including ringing of a coupled TLP in steep nonlinear irregular waves. The technique for generation of realistic steep nonlinear irregular waves in a wave tank is a pressing need.

INTRODUCTION

Investigation of the ringing effect on offshore structures such as gravity-based structures (GBS) and tension-leg platforms (TLP) is being carried out in the offshore industry. Ringing is a high-frequency structural response in the form of transient energetic bursts (Natvig, 1994; Davies et al., 1994; and Jefferys et al., 1994) and is generally understood as a natural frequency response of the structures due to weak impulse load (or impact) caused by the action of steep nonlinear nonbreaking waves.

In studying ringing, a few unsolved problems have been identified by Natvig, Davies et al. and Jefferys et al. Two problems are most difficult and pressing, i.e., accurately calculating wave kinematics from measured wave time series, and modelling of nonlinear wave loads including weak impact.

The present authors have recently been working on the same problems and found an excellent model for kinematics near the surface of steep nonlinear irregular waves and nonlinear wave loads on a fixed ISSC-TLP column (diameter = 16.4 cm, draft = 30 cm).

Three typical steep nonlinear waves are generated, i.e., an energetic transient group wave, a Stokes higher-order-like nonlinear irregular wave and a Stokes 5th-order-like nonlinear regular wave. Predicted and measured horizontal velocities and wave forces are in excellent agreement. The basic assumption is that the nonlinearity of the measured wave elevation time series is linearly transferred to that of the particle velocities as well as wave forces on the TLP column.

BASIC CONCEPT OF PREDICTION MODEL

We want to predict wave particle kinematics below the wave surface and wave force on a structure affected by laboratory-generated physical nonlinear irregular waves.

We designate the measured nonlinear irregular wave time history given as excitation and particle kinematics, and wave forces as unknown nonlinear irregular responses.

FFT of the excitation and response time series yields both input and output amplitude spectrums that are linear because they are constituted of many sinusoids. If we determine appropriate linear transfer function between the input and output spectrum, we can predict the output spectrum by multiplying the linear transfer function to the measured input amplitude spectrum. Then IFFT of the complex output amplitude spectrum yields the prediction of the nonlinear irregular response time history.

Whether this model is applicable or not totally depends on whether the appropriate linear transfer function can be found. Therefore, the major effort in applying the model is to find an appropriate and accurate linear transfer function between the input and output amplitude spectrum.

This linear system model is totally new and unique in that it can be applied to predict diverse nonlinear irregular responses of fluid and structure affected by measured nonlinear irregular waves.

GENERATION OF NONLINEAR WAVES AND MEASUREMENT OF PARTICLE VELOCITIES AND FORCES IN 2-D WAVE TANK

The wave tank is 37 m long, 0.91 m wide and 1.22 m deep and is equipped with a Commercial Hydraulics RSW90-85 dry back, hinged-flap wavemaker, and downstream wave energy-absorbing beach.

A steep nonlinear nonbreaking transient wave group is generated by the wave flap driven by a signal numerically produced by PC. Details are given in Kim et al. (1990,1992). A Stokes higher-order-like nonlinear irregular wave is generated by producing a JONSWAP irregular wave of significant wave height: 10 cm. A Stokes 5th-order-like nonlinear regular wave has the period and height of 1.20 s and 25 cm, respectively, which are approximately equivalent to those of the transient wave but the profile is symmetric about the vertical axis. In order to avoid any reflection, we record the waves for 20 s, 10 s and 10 s, respectively, for transient, Stokes higher-order-like irregular and 5th-order-like regular waves. The water depth is 0.8 m, and the wave gage is located at 14.05 m from the wave flap. In the transient wave design, we use input data: wave height of 25 cm, constant wave slope of 0.28 and water depth of 0.8 m. The transient wave characteristics are similar to the previous one in Kim et al. (1990, 1992) but not identical due to different water depth. The horizontal and vertical velocity time series are obtained simultaneously with the wave

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