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Inundation Effect of Wave Forces on Jack-up Platforms

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ABSTRACT

This paper aims to study the importance of the wave inundation effect. A concentrated force acting at the mean water level of the platform leg is used to represent the inundation effect due to variable wave surface. Its effects on the total and maximum wave forces are investigated based on structural modal analysis and linear wave assumptions. After the inundation drag force is approximated as an asymmetric second-order term, the corresponding frequency-domain transfer functions of Volterra/Wiener representation are derived. The auto-spectra of the deck displacement of 2 typical jack-up platforms are numerically evaluated to show the significant contribution of the inundation effect to the structural dynamic responses.

INTRODUCTION

Considerable works have already been carried out by many researchers in the study of nonlinear wave forces on jack-up platforms. It is commonly accepted that nonlinear dynamics has a significant effect on the response of many jack-up structures, and 2 main nonlinear effects are attributable to wave forces. One is the effect of the nonlinear drag force, which is usually the predominant wave-force component for the slender structural members of a jack-up platform and can be evaluated using the well-known Morison formula. The other nonlinear effect can be related to the variable submerged height of structural members near the free water surface, or the inundation effect (Tickell and Bishop, 1985; Tung, 1996). The common practice by which to include nonlinear effects in dynamic analysis is to perform time-history simulations. In order to have statistically meaningful results, many such time-consuming simulations are usually required. A more direct approach is to carry out stochastic analysis in frequency domain. However, nonlinear frequency-domain analysis is much more involved than the normal approach based on linear assumptions.

One well-known method of modelling nonlinear systems in stochastic analysis is Volterra series representation (Schetzen, 1980; Rugh, 1981) of nonlinearity by a polynomial expansion. Since this procedure involves multivariable Fourier Transform, the derivation and numerical evaluation of high-order nonlinear systems can be very tedious. For the nonlinear drag term in the Morison equation, Borgman (1969) suggested a cubic approximation without current. Gudmestad and Connor (1983) included the effect of current using a fourth-order expansion. Third-order Volterra series and related transfer functions were studied by Li et al., (1995) and Tognarelli et al. (1997). These above authors showed that, with the cubic drag term included, the structural response spectrum exhibits a significant resonance phenomenon near the frequency $3\omega_p$, where ω_p is the peak frequency of the wave spectrum.

The nonlinear inundation effect due to variable water surface, on the other hand, produces even-order superharmonic force components (Gudmestad and Poumbouras, 1988), which cause the force spectra to have peaks at $2\omega_p$. Typically, the fundamental frequency of a jack-up offshore platform is in the range of 0.25 to 0.12 Hz (Kjeoy et al., 1990), which is about 2 to 3 times the peak wave frequency. The nonlinear responses near $2\omega_p$ can therefore be very significant. The inundation effect, however, was not included in the above-mentioned works of nonlinear frequency-domain analysis of offshore platforms. In this paper, in order to compare the effects of the distributed Morison force and inundation force, the case of sinusoidal waves is studied first. Since the inundation effect introduces only even-order wave forces, quadratic approximation is reasonable, especially for structures with fundamental frequencies not higher than $2\omega_p$. The least squares method (Bendat, 1995) is applied to obtain the quadratic coefficient. The second-order frequency response function of wave forces and the power spectral density functions of the modal force and displacement are derived. Results of nonlinear stochastic analysis of 2 typical jack-up platforms are then presented to show the effects of inundation.

INUNDATION EFFECT

The Morison wave force per unit length $f(z,t)$ of a structural member is given typically as:

$$f = k_M \frac{\partial u}{\partial t} + k_D |u| u \tag{1}$$

where $u = u(z,t)$ is the water particle velocity normal to the structural member, and k_M and k_D are the appropriate inertia and drag constants, respectively. To better demonstrate the nonlinear effects of inundation, one leg of the platform is considered and the structural system is assumed to be linear. Further, the hydrodynamic coefficients, k_M and k_D, are assumed to be constants along the height of the platform leg. If the mode-superposition method is applied to solve for the structural responses, the modal force F is obtained by integrating the product of the structural mode shape, Φ, and the distributed wave force f:

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KEY WORDS: Inundation effect, jack-up platform, nonlinear wave spectral analysis, Volterra series, least squares approximation.