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Responses of an Articulated Tower in Waves and Currents

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ABSTRACT

The responses of an articulated loading platform (ALP) in random waves and currents are investigated both in frequency and time domain. The first- and second-order wave diffraction-radiation is solved by the ring source boundary integral equation method, and the viscous drag forces are computed from the modified Morison equation using relative velocity squared. In the frequency-domain analysis, the nonlinear drag is stochastically linearized and the resulting equation is solved iteratively. In the time-domain analysis, the nonlinear equation — including the quadratic drag term and a convolution integral — is directly integrated using a Newmark-beta method. From our numerical examples, it is shown that the slowly varying resonant responses in random waves are significant compared to wave-frequency responses when there is no current or when the current is normal to the wave direction, while they are greatly reduced when there exists strong in-line (coplanar or adverse) current. However, the presence of strong in-line current significantly increases the mean pitch angle.

INTRODUCTION

During the past several decades, articulated columns have been increasingly used in many offshore areas as production systems and offshore loading terminals. Because the natural frequency of the ALP in pitch/roll mode is typically much smaller than ocean wave frequencies, the linear theory alone is not adequate to estimate the resonant pitch responses. It is actually shown in this paper that the second-order difference-frequency wave excitations cause large-amplitude, slowly varying responses in typical random seas, and the rms value of the low-frequency response is comparable to or can be even greater than that of wave-frequency motion depending upon the available damping and the size of the ALP. This phenomenon has been observed in Sincock's (1989) model test. In addition, the magnitude of the slowly varying responses is known to be very sensitive to the velocity and direction of currents.

In order to illustrate the above phenomena, an ALP model given in Naess (1980) is selected and its responses in random waves with or without currents are computed both in the frequency and time domain. We assumed that the current is uniform and steady. When current exists, the magnitudes of both wave-frequency and slowly varying excitations are affected through nonlinear wave-current-body interaction, which is not pursued here. Instead, the current effect is approximately estimated through the nonlinear drag term and the modification of the frequency and amplitude of the input spectrum. Both frequency- and time-domain response calculations are carried out for various current speeds and directions.

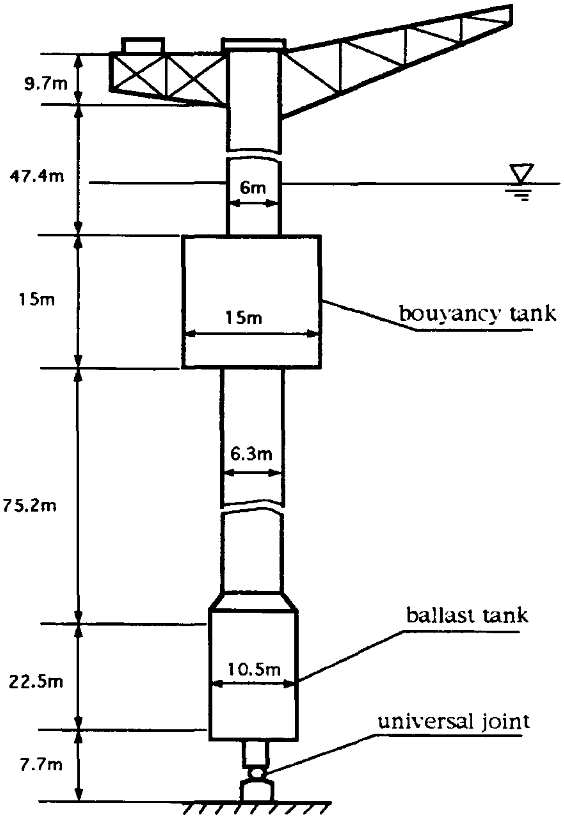

Fig. 1 Articulated loading platform

MOTION ANALYSIS

The ALP used in our numerical examples is shown in Fig. 1. The particulars of this articulated column are summarized in Table 1. We only consider the rigid body pitch motions in unidirectional waves; the possible vortex-induced transverse vibration is not taken into account here.

The equation of the pitch motion is:

$$(I+I_a)\ddot{\theta}+c_w\dot{\theta}+K\theta=M \qquad (1)$$

in which θ is the pitch angle, I the moment of inertia of the structure, I_a the added moment of inertia, c_w the wave damping coefficient, and K the restoring moment coefficient caused by the buoy-

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KEY WORDS: Slowly varying responses, waves and currents, second-order excitation, stochastic linearization, frequency- and time-domain analysis, two-term Volterra series.