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Experimental Study of the Ringing Response of a Vertical Cylinder in Breaking Wave Groups

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ABSTRACT

Systematic experiments were carried out in a wave-tank in order to investigate the high-frequency resonant response of a flexibly mounted vertical cylinder due to waves. For this lightly damped structure, ringing responses with high structural accelerations were observed in breaking wave groups. Structural deflections (first bending mode) have also been measured. Ringing appears initiated by the impact of the deformed and breaking wave on the cylinder. The loads acting on the cylinder have been deduced from the measured response and appear to be closely correlated with the local wave slope at the cylinder. Complementary measurements of the response of the cylinder to loadings in Stokes waves were also made for a range of structural natural frequencies including the third harmonic of the wave frequency. These are shown to be distinct from ringing responses. The comparison between Stokes wave and deformed wave response is heightened through spectral analysis.

INTRODUCTION

In order to gain understanding of the physical mechanisms involved in the observed excitation of the structural response of large ocean structures by North Sea wind waves, experimental hydroelastic studies have been carried out in the Ocean Engineering Laboratory at the University of California at Santa Barbara. Experimental techniques continuously evolved through a series of three different tests beginning in 1996 and concluding in April 1998. Chaplin et al. (1997) has conducted in the U.K. very similar experiments with results overlapping those found here.

The ringing phenomenon, first identified in the early Eighties, can be described as a transient resonant response of the structure, and many studies of it have been undertaken. According to Davies et al. (1994), ringing is associated with asymmetric waves of maximum crest height, preceded by a shallow trough, which are found on the forward portion of wave groups. Jefferys and Rainey (1994) suggest that ringing is caused by a fast rise to the peak of the wave, implying large horizontal accelerations and velocities in the wave crest. Chaplin et al. (1997) found that the maximum moment acting on the cylinder occurred at about the same time as the vertical velocity on the free surface at the cylinder axis (these vertical velocities were measured without the presence of the cylinder). According to Kim et al. (1997), ringing is due to weak impact, caused by steep asymmetric nonbreaking waves. Zou and Kim (1996) carried out an experimental study measuring both wave elevation and horizontal force acting on the cylinder. They pointed out the necessity to undertake further studies concerning the origin of the high-frequency component of the force during the rise, as well as the effects of the wave slope.

At the same time, different models have been proposed to compute the cylinder loading due to these steep nonlinear asymmetric waves. In Davies et al. (1994), Jefferys and Rainey (1994), Kim et al. (1996) and Scolan et al. (1996), the fluid velocities and accelerations were found from a spectral analysis of the temporal record of the free-surface elevation, and a transfer function from linearized theory was used. In order to take into account the real position of the free surface, these values were eventually corrected using a stretching model. Instead of using a stretched linear theory for particle kinematics, Chaplin et al. (1997) used a quasi-steady nonlinear one. The loads are then computed by integration of the Morison equation along the cylinder. Additional loads, such as those due to impact (surface interaction terms), are generally included in these models.

Other systematic mathematical developments have been undertaken by Faltinsen et al. (1995) and Malenica and Molin (1995) in the range $r/a = O(1)$ (r is the cylinder radius and a the amplitude of the incoming wave). The former study addresses the nonlinear near field but assumes long waves and a linear wave in the outer field. The latter is a consistent asymptotic expansion to third order in ak; i.e., it assumes the outer field to be a Stokes wave. Neither of these studies addresses the effect of deformed asymmetric waves, or breaking waves, nor is the region of validity of the approximation clear even in the case of Stokes waves.

Ringing response of vertical cylinders in steep random waves has been studied by Stansberg et al. (1995) and Marthinsen et al. (1996). Chaplin et al. (1997) generated focused waves in the vicinity of the cylinder. In the present study, attention is focused on the ringing response due to waves at various stages of breaking. The seeded sideband technique was adopted to generate breaking wave groups. This technique is based on the theoretical work by Benjamin and Feir (1967). Stokes waves are unstable to suitable sideband perturbation, leading to the formation of wave groups where the carrier wave eventually breaks at the peak of the modulation (Tulin et al., 1994). As shown by Tulin and Waseda (1999), prescribing the sidebands at the wave maker results in a precise control of the down tank evolution of these wave groups. In this way, the modulated wave can be caused to break repeatedly in the vicinity of the cylinder. The average energy density in the wave group system is determined by the steepness ak_0 of the carrier wave at the wavemaker. Due to the modulation, the wave energy becomes concentrated at the wave group peak, where eventually the waves deform and then break. Testing in wave groups thus allows the response to a wide variety of waves; these

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