Effect of Ramp Duration on Response of Spars to Irregular Waves

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ABSTRACT

In model testing of offshore platforms in wave basins it is customary to apply the wave excitation gradually increasing its amplitude over a given period of time. This is often referred to as a loading ramp. The presence of a ramp is practically important when dealing with very flexible structures with very small values of damping since in these cases the free vibrations associated with the initial conditions can lead to responses during the transient much higher than those expected under stationary conditions. Without the ramp it might not be possible to reach the stationary response within the duration of the test, which is limited by wave reflections.

This paper presents results of studies conducted at the Offshore Technology Research Center intended to investigate the effect of the ramp duration on the measured responses particularly after the end of the ramp over the latter part of the excitation when a stationary condition should have been reached. The results presented include time histories of response of a Spar platform subjected to irregular waves as well as the Fourier amplitude spectra of these motions. Of particular importance in these spectra are the peaks at the natural frequencies of the platform associated with nonlinear (difference frequency) effects but also due to the free vibration terms. The analyses were conducted using slender body theory with a number of modifications intended to account for various diffraction effects.

INTRODUCTION

The concept of spars is not recent. It has existed for decades. However, using spars as production platforms is relatively new. The interest of the oil industry in spars was sparked by the discovery of large amounts of oil in deep water. Since then, offshore oil designers started looking for innovative ways to extract oil from deep water where using fixed jacket structures is no longer feasible. The spar has been one of these promising solutions due to its inherent stability characteristics. The spars, in general, have long natural periods in all six degrees of freedom, which are much longer than the dominant wave periods. This eliminates the nonlinear effects associated with sum frequencies (higher harmonics) leaving only difference frequency terms as potentially important nonlinear effects.

Experimental tests of spar models showed large amplitude responses at the difference frequencies (slowly varying drift motion) (Mehma et al., 1995), (Ran et al., 1995). Because the duration of such tests were short, it was not determined if such motions were due to nonlinear effects of the applied forces and the structural geometry or to the free vibration at the structure's natural frequencies caused by the initial conditions. Although, the analytical programs (Mehma et al., 1995), (Ran et al., 1995) were able to capture the motions at the difference frequencies for the specified period of the experimental tests, there have been long discussions about whether such motions will disappear and die out with time. The experimental results do not provide such proof because of their short duration and the effect of wave reflections in wave basins.

In this paper an attempt is made to investigate the effect of the duration of the gradual increase of the applied forces using a ramp on the behavior of the spars. For this purpose, the duration of the ramp is changed and the analyses are allowed to last longer than in the experiments. The time histories and the associated Fourier amplitude spectra (FAS) for different ramp durations are plotted. The paper clearly shows that large motions at the structure's natural frequencies appear due to the initial conditions but die out when the wave forces are applied gradually over a long period of time. In actual seas the waves will take a long time to build up during a storm or hurricane. One must therefore use an appropriate initial ramp in the tests if the results are to be representative of field conditions.

ANALYTICAL MODEL

The spar structure (Figure 1) is modeled as a rigid body with three degrees of freedom at its center of gravity; namely, surge, heave and pitch. The keel of the spar is closed and the effect of a pumping mode of motion is avoided (Weggel and Roesset, 1995). The equations of motion for the spar structure are written as:

\[ M\ddot{U} + C\dot{U} + KU = P(t) \]