International Journal of Offshore and Polar Engineering
Vol. 12, No. 3, September 2002 (ISSN 1053-5381)

Ringing of Heidrun TLP in High and Steep Random Waves

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ABSTRACT

Ringing of the Heidrun TLP due to phenomenal laboratory sea waves was successfully simulated and validated with model test data. A model UNIOM was employed to calculate 1-h-long laboratory, nonlinear steep-random-wave loads on the TLP. The simulation of the nonlinear response of the coupled TLP due to the wave loads gave nearly the same typical statistical features and magnitudes as the high-frequency tension distribution observed from the model test data.

INTRODUCTION

Stansberg et al. (1995) conducted an experimental study of nonlinear loads on vertical truncated cylinders due to the waves that had previously caused ringing in the Heidrun model tests. We applied the above replica of the Heidrun ringing wave directly to calculate the nonlinear wave loads on the platform, using a universal nonlinear input-output model (UNIOM); consequently, we simulated a ringing response of the Heidrun TLP. The 2nd-order diffraction theory has been well developed for computation of the 2nd-order wave forces due to 2nd-order waves and other linear responses. However, as the nonlinearity of the ringing wave was much higher than the 2nd-order, the conventional application of the 2nd-order diffraction theory due to the Gaussian (linear) random wave of the target spectrum (Volterra quadratic model, Dalzell and Kim, 1979) would no doubt highly underestimate the wave loads. Because the industry had a pressing need for simulation of the ringing due to the above steep waves, researchers sought other avenues of approach.

The first one was to develop a 3rd-order diffraction theory (Faltinsen et al., 1995; Malenica and Molin, 1995), but the result was the 3rd harmonic term alone among the complete set of 36 3rd-order terms. Thus the 3rd-order theory had limitations for the above purpose (Kim and Wang, 1999a). The second approach was to find the applicability of the Numerical Wave Tank (NWT), whose feasibility was studied through an NWT review (Kim et al., 1999), but its applicability did not lie in the foreseeable future.

The last approach was made recently by Kim and Wang (1999a): They proposed and verified a model ULSM—renamed here UNIOM—against the nonlinear measured loads on the fixed vertical cylinder due to the replica of the Heidrun ringing wave (Stansberg et al., 1995). In the above, as UNIOM employed an LTF (linear transfer function) and a QTF (quadratic transfer function) for diffraction of the ringing wave, and as the diffraction theory must be valid for arbitrary shape structures, there was no question about the validity of applying UNIOM to the wave loads on the Heidrun TLP due to the ringing wave. Indeed, this model made a breakthrough in computing the much higher nonlinear wave load that had led to the successful simulation of the ringing response of the Heidrun TLP. The result was statistically similar when compared with the typical, measured high-frequency tension distribution that caused the ringing, and the ringing waves causing the ringing tensions had characteristics similar to the observed waves (Natvig, 1994; Davis et al., 1994).

HEIDRUN'S DESIGN PARTICULARS

The original design had 4 tethers on each column being attached on the porch. For the current simulation, we estimated 4 equivalent tendons connected to the centers of the columns' bottoms that give the equivalent stiffness for the surge, heave and pitch mode. The outer and inner tether diameter was chosen so as to give the equivalent stiffness of the 4 small-diameter tendons. The natural frequencies of the 3 modes of motions of the platform were determined approximately with $\sqrt{Stiffness/Virtual\,Mass}$.

ENVIRONMENTAL LOADS

We assumed steady wind (38.8 m/s) and current (1.0 m/s) on the ocean surface concurrent with the long-crested ringing waves in the head-sea condition. Thus the waves induced the hydrodynamic surging, heaving and pitching loads that produced the surge, heave, pitch and tendon tension response. UNIOM with LTF and QTF computed the wave-exciting forces on the platform due to the measured ringing wave. The viscosity effect was computed by the Morison equation considering the relative velocity of the wave particle and mean current to the entire wetted moving body below the mean water level. The wave particle velocity was estimated from the target wave spectrum for the Heidrun ringing wave. For the mean wind load and mean current distribution, the formulas recommended by API (1987) were used. The wind load was the major contributor to the offset of the platform, while the mean drift force was a minor contributor. The viscous excitation was negligibly small compared to the hydrodynamic exciting forces.

HEIDRUN RINGING WAVE

The Heidrun ringing wave was regenerated from the target spectrum JONSWAP $H_s = 15.4$ m, $T_p = 17.8$ s and $\gamma = 1.7$ (Stansberg et al., 1995). The total record was about 3.5 h long; the present study employed the first part of the 1-h-long data. We found that the variance of the measured wave was very close to that of the target spectrum, which indicates a high quality of wave generation. The skewness of the wave was 0.274, but we needed to

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Received September 1, 2001; revised manuscript received by the editors June 14, 2002. The original version was submitted directly to the Journal.
KEY WORDS: Heidrun ringing wave, ringing, Volterra quadratic model, universal nonlinear input-output model, ULSM.