

Prediction of Deepwater Oil Offloading Buoy Response and Experimental Validation

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Fully coupled time-domain approaches were applied to predict the vertical plane motions, i.e. surge, heave and pitch, of the deepwater buoy. It is found that the pitch motion in particular is sensitive to the drag effect of the skirt, and is coupled with both surge and heave motions, and that a time-domain fully coupled analysis can capture the viscous drag effect. Results from 2 experiments, one with a freely floating buoy and the other with a moored buoy, are presented to show that the proposed time-domain coupled analysis predicts the buoy motion behavior very well for both cases compared to frequency-domain analyses with a linearized stiffness for the mooring system. Comparison of experimental data and coupled analysis results from the proposed buoy skirt modeling with multiple disks shows that viscous modeling of the buoy skirt by applying a Morison drag force formulation based on relative velocity can be used to better predict the pitch motion.

INTRODUCTION

Since the first catenary anchor leg mooring (CALM) system was employed in 1961, this system has been extensively applied as a loading/offloading terminal (Hwang, 1997). As the current major oil and gas fields are getting depleted, new potential fields in deep and ultra-deep seas are getting more and more attention (Ryu and Kim, 2003). This results in developing the CALM buoy system in deep waters, an application whose dimensions and hydrodynamic characteristics differs from that in shallow waters.

Deepwater offloading buoys are being extensively used in West Africa to allow efficient loading of spread-moored FPSO. Some of the current projects of the offloading buoys include Agbami (Nigeria, 1435-m water depth), Akpo (Nigeria, 1285-m), Bonga (Nigeria, 1000-m), Dalia (Angola, 1341-m), Erha (Nigeria, 1190-m), Girassol (Angola, 1320-m), Greater Plutonio (Angola, 1310-m) and Kizomba A & B (Angola, 1200-m and 1000-m).

Deepwater offloading buoys have a relatively small displacement when compared to other floating systems such as TLP, spar and FPSO, with the majority of the displacement being used to support the mooring system and the oil offloading lines. This results in a floating system that has a very active response to the environment, coupled with feedback from the mooring and flowline systems. In addition, compared to other floating systems, deepwater offloading buoy systems have relatively unique system identifiers (i.e. inertia, damping and stiffness). In other words, the orders of the total mass of the mooring lines and oil offloading lines (OOL), the viscous damping due to a skirt, and the stiffness from the mooring lines and hawsers are considerable compared to those of the inertia, radiation damping and hydrostatic stiffness of the buoy, respectively.

As the operating water depth increases, prediction of full 6 degree-of-freedom (DOF) motions of the offloading buoy becomes more difficult because the mass/damping/stiffness contribution of mooring system and oil offloading lines becomes even

more influential than that of the buoy. Thus, the coupling between mooring lines/oil offloading lines and the buoy hull becomes more complex.

A time-domain coupled analysis of a CALM system was performed based on both radiation/diffraction and Morison's equation (Sagrilo et al., 2002). In that work only statistical results—such as mean value, standard deviation and most probable 3-h maximum value, for surge, heave and pitch of a CALM buoy and 6 mooring lines—were calculated and compared to available model test results. However, the RAO of those 3 buoy motions in a vertical plane were not directly compared to the model test results. As the riser/mooring/hull coupling becomes more significant in deeper waters, the coupled analysis is emphasized to better predict the motion of the floater and line dynamics (Ormberg and Larsen, 1998). Frequency-domain coupled analysis was discussed in terms of computational efficiency without loss of accuracy compared to time-domain coupled analysis of floating production systems (Garret, 2005).

Cable-buoy coupled motions of 3 different types of tethered buoys (disc, sphere and spar buoy) were studied (Leonard et al., 2000). Because the buoy pitch motion is less accurate than the other 2 motions, i.e. heave and surge (Leonard et al., 2000; Sagrilo et al., 2002), more accurate pitch motion prediction is required to better assess other buoy design issues such as fatigue life.

The motion behavior of this buoy system has been shown to result in severe fatigue damage to the mooring and flowline components (Heyl et al., 2001), and thus must be estimated accurately to ensure that the system is designed with sufficient fatigue life.

In a deepwater buoy system it is necessary to identify and implement the effect of both inertia and viscous loadings on each object of the buoy system, as the fundamental natural periods of the buoy are in the range of 1st-order wave loading, and the system is sensitive to damping. Bunnik et al. (2002) conclude that the pitch motion cannot be well predicted when the viscous effects of the skirt are neglected. Cozijn and Bunnik (2004) also found that the pitch motions were overpredicted and suggested that this may come from nonlinear viscous effects in the wave exciting pitch moment.

In this study, in order to accurately predict the buoy pitch motion by applying the Morison equation as the viscous effect, a fully coupled time-domain analysis and a diffraction model of the buoy with viscous drag elements are employed. This paper's

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