

## **Improved Prediction of Full-Scale Roll Motions for Vessels with Large Liquid Tanks**

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### **ABSTRACT**

Accuracy of roll motion predictions can vary significantly for floating vessels with large liquid tanks. Historically, most of the attention has been given to properly modeling roll damping. While we agree on the importance of such efforts, in this paper we show that common practices for modeling the mass of liquid in the tanks also can be a significant source of roll prediction error. The most common source of error we see is the use of rotational mass moment of inertia from formulas that are correct only for solids. The results we present in the paper demonstrate the potential for dramatic improvement in roll prediction when we include both of the following elements:

- 1) roll damping using ExxonMobil's modified Himeno empirical formulas with stochastic linearization; and
- 2) explicit modeling of liquid motion in large tanks accounting for tank geometry, liquid properties, fill level, and first order response to tank boundary motions.

The prediction improvements cited in this paper are relative to physical measurement at model and full scale. By sharing these results, we believe that integrating our findings into marine practices for roll motion will lead to a consistent level of reliable predictions for designers that serve our industry.

**KEY WORDS:** FPSO; roll; roll damping; full-scale; liquid cargo.

### **INTRODUCTION**

Roll motion is one of the very important factors that need to be included in FPSO topsides design, hull structural design, riser and mooring leg design. It is also very important to the safe LNG transfer between an offloading terminal (fixed or floating) and the LNG carrier.

In the roll motion prediction of floating vessels, the external force components that govern the roll motion are the potential flow components (added mass, potential damping and wave exciting forces) and the viscous roll damping force. Extensive validation studies exist in the public domain to support practical application of potential flow methods for large floating bodies including tankers and FPSOs (Faltinsen, 1979; Østergaard and Schellin, 1987).

The most significant uncertainty in conventional roll prediction is associated with the viscous roll damping. Current industry analyses for ships and FPSOs use empirical formulas of the roll damping (Himeno, 1981; Ikeda et al., 1978; Ikeda et al., 1993; Schmitke, 1978; Standing and Jackson, 1992). The roll damping empirical formulas, called Himeno or IHT formulas, developed by Himeno (1981) or by Ikeda, Himeno and Tanaka (1978, 1993) are widely used in the offshore industry nowadays. Those formulas are from tests using small-scale models in calm water (Himeno, 1981; Ikeda et al., 1978; Ikeda et al., 1993). For a 250-300 m long FPSO hull, the model scales of those tests are in the range of 1:150 ~1:200.

Validation of empirical formulations for viscous roll damping requires:

- 1) Predictions from small-scale data agree full-scale motion response;
- 2) Predictions from calm-water formulation are applicable in irregular waves; and
- 3) Linearization methods are reliable for conventional frequency domain analyses

In studies conducted at the University of Michigan by ExxonMobil in the mid 80's (Troesch and Beck, 1987) we found that Himeno formulas over-predicted roll damping for hulls with small bilge radius, which under-predicted roll motion. As part of that effort, ExxonMobil developed modifications to original Himeno formulas to account for small bilge radius hulls. ExxonMobil's modified Himeno formulas have been verified against large scale model tests previously done with barge shaped hulls at Michigan (Troesch and Beck, 1987) and a VLCC hull test from the MARIN FPSO ROLL JIP (2006b).

A common approach for roll motion prediction includes the following elements:

- 1) hydrodynamic forces on vessel is computed with three dimensional diffraction codes;
- 2) viscous roll damping is computed with various kinds of empirical formulas such as Himeno (1981) and Schmitke (1978);
- 3) liquid cargos are models as stationary solid masses for each tank; and