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Prediction of Course Stability of Towed Offshore Structures by Computational Fluid Dynamics

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The purpose of this research is to find practical methods to predict the course stability of towed offshore structures at the initial design stage. The equilibrium yaw angles of a towed Floating Production Storage and Offloading (FPSO) with a single skeg and twin skegs are predicted by a drift model test and a Computational Fluid Dynamics (CFD) analysis. The results are compared with the towing model test results. Additionally, CFD towing simulations are performed and validated, and the mechanism of instability is analyzed through an investigation of physical quantities obtained from the CFD simulations.

INTRODUCTION

The demand for offshore structures such as Floating Production Storage and Offloadings (FPSOs) and semi-submersibles has increased in order to develop offshore oil and gas fields. Offshore structures constructed at shipyards should be transported safely to the oil fields. They are generally towed by several tugboats and towing lines. Defined as whether the towed offshore structure follows the desired course of the tugboats, the course stability is one of the indices for safe transportation. If the course stability is not secured enough, it will be difficult to keep the course, and eventually the overall transportation may fail in the worst case. If the transportation fails, the risk of collision with other vessels or geographic features increases, which may lead to damage to the towed offshore structure or even a catastrophic oil spill.

Governed by the submerged hull form, the hydrodynamic characteristics can change the course stability. In other words, transportation safety starts from the design stage of the hull form. Therefore, the prediction of the course stability is one of the most important aspects of the design and engineering of offshore projects. Much research has been done on the prediction of the course stability. Strandhagen et al. (1950) investigated the course stability criteria for the towed vessels using the Routh-Hurwitz stability criterion. Bernitsas and Kekridis (1985) suggested the discriminant using characteristic equations derived from the equations of motion of the towed vessel.

As of now, the prediction of the course stability of towed vessels at the design stage heavily depends on the model tests in marine industries. Latorre (1988) investigated the scale effect on the course stability of towed barges. He found that the model resistance was larger than the full-scale resistance. On the basis of his findings, he indicated that the model barge might overestimate the course stability compared to the full-scale barge due to the scale effect. You (2000) carried out the towing model tests for a tanker ship and an FPSO. He found that the FPSO achieved better course stability than the tanker. Jung et al. (2005) performed the towing model tests to investigate the bow shape effect on the course stability of FPSOs. Two different types of bow shapes were tested: a barge bow shape and a spoon bow shape. It was found that the barge bow shape obtained better course stability than the spoon bow shape. Yang and Hong (2006) carried out extensive towing model tests for different stern hull shapes, skegs, and bilge radii for an FPSO. Kwon (2007) performed the towing model tests for the forward blocks of container ships and tankers. The towing model tests showed that the container blocks were towed with a fishtailing motion. Yang et al. (2011) investigated the interactions between a tugboat, tow lines, and a towed vessel through two different modelings of tugboats, in which the FPSO model was directly towed by a carriage and towed by a free-sailing tug model.

As previously mentioned, the model test is widely used for its reliability, but there are many limitations such as time, cost, measurements, and test facilities. It is also extremely difficult to redesign the hull form after the model test by reason of the poor course stability since the basic design is nearly finished at the model test stage. More importantly, it is difficult to understand the resulting instability with limited data from the model test.

Besides the model test, numerical approaches have been studied. Yasukawa et al. (2006) carried out the numerical towing simulations with a 2D lumped mass model to express the dynamics of tow lines. Captive model tests were carried out to capture the hydrodynamic coefficients of barges. The simulation results were compared with the towing model test results. Nam et al. (2012) performed the numerical towing simulations using MMG (Mathematical Maneuvering Model Group) and a cross-flow model and compared the simulation results with the model test results. Fitriadhy et al. (2013) investigated the wind load effect on the course stability of a ship towing system using numerical analysis. Towing simulations in various conditions are possible through numerical approaches. However, the hydrodynamic characteristics of the vessels must be known in advance. Empirical or regression formulas can be applied to estimate the hydrodynamic coefficients, but

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