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Dynamic Response of Oscillating Flexible Risers Under Lock-in Events

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A highly nonlinear response and a self-regulated process are usually associated with the dynamic response of a flexible riser. In addition, the formation of vortices shedding from the riser related to Vortex-Induced Vibration (VIV) may adversely affect its structural integrity. In this paper a response prediction model for oscillating flexible risers is presented. It is based on the Finite Element Method (FEM) and a harmonic model for the prediction of the cross-flow forces. An increased mean drag coefficient model and amplitude-dependent lift coefficients are also considered. The simulation results are compared with experimental data obtained from a 35-m riser model. Good agreement in amplitude response is observed in these comparisons.

INTRODUCTION

One of the main challenges of deep petroleum production is the response prediction of the riser system employed to transport oil from the seabed to floating offshore structures. A complex dynamic response and considerable economical impact due to large structural degradation, mainly caused by vortex-induced vibrations (VIV), are commonly associated with deep-water risers. In addition, the resonant-type VIV, when the vortex shedding frequency approaches, or is coincident with, a natural frequency of a riser, may cause considerable cross-flow oscillations of the riser. The VIV analysis of a deep-water riser is still challenging due to the fact the riser can be excited along its length in different modes and at different frequencies, leading to a modal response dominated by mode interference, multi-mode response, mode switching and frequency dependence of the added mass. Basically 2 approaches are widely used to predict the dynamic response of a flexible riser; the main difference between these is related to the procedure employed to compute the hydrodynamic forces.

The first approach usually incorporates a computational fluid dynamics-based procedure to solve the Navier-Stokes equations in order to obtain the hydrodynamic forces in 2-dimensional planes and then input them into an FE model of a riser. This approach has many limitations considering the large number of variables that must be included in the analysis. The fluid motion and the motion of the riser must be coupled in order to obtain a good prediction model, especially under lock-in events. However, it is still challenging to numerically predict the dynamic behavior of this coupled system. The second approach is referred to as semi-empirical. In this approach the hydrodynamic force coefficients obtained from experiments are used to compute the forces acting on a riser. Existing semi-empirical models use large databases of experimentally determined coefficients to predict VIV. Thus, the accuracy of the response prediction is strongly related to the experimental data available for the modeling conditions involved in a simulation. As a result, the lack of data can lead to inaccurate results, especially if lock-in events are likely to occur.

Using experimental data and 11 different response prediction models, Chaplin et al. (2005) showed the semi-empirical approach is more successful than the CFD-based approach at predicting the cross-flow response of a flexible riser. They concluded that the in-line VIV curvatures, which are as dangerous as cross-flow curvatures, could not be predicted by any of the semi-empirical models used in their comparisons. Several experimental studies for flexible risers in sheared flow have been carried out in the past 3 decades, leading to the development of empirical formulations that are currently used in semi-empirical models. One remarkable example is the Strouhal number, sectional r.m.s. lift coefficient and one-side span-wise correlation formulations developed by Norberg (2003) for a wide range of Reynolds numbers ($Re = 47$ to 2×10^5). However, many researchers have also pointed out that the response of a flexible riser under lock-in events shows sudden changes in the values of the lift force coefficients needed for semi-empirical models. Further, the mass ratio of a riser (calculated as the mass of the riser divided by the mass of the fluid displaced) influences the nature of the dynamic response of a flexible riser.

Duggal and Niedzwecki (1995) conducted a large-scale experimental study to investigate the dynamic response of a riser model constructed from ABS plastic tubing 17.18 m long, 0.032 m in diameter, and pinned at both ends. The model was excited at Keulegan-Carpenter (KC) numbers ranging from 10.6 to 52.7. Based on the analysis of the experimental data, Duggal and Niedzwecki (1995) concluded that the cross-flow response shows similarities with previous research work using oscillatory flow in rigid cylinders. According to Chaplin et al. (2005), the response

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