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Laboratory Investigation on the In-Line Dynamic Characteristic of Long Flexible Riser Under Vortex-Induced Vibration

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ABSTRACT

This work presents the experimental results focused on the dynamic characteristics of in-line response of a long flexible riser. The riser model is 28.04 m in length and 0.016 m in diameter, giving an aspect ratio (length to diameter) of around 1750. The mass ratio (structural mass over displaced fluid mass per unit) of the riser model approximates 1.0. By means of towing the riser model in a wave basin, the uniform current was generated. The time series of strains of the riser model under various current speeds (ranging from 0.15 m/s to 0.60 m/s) were monitored using the Fiber Bragg Grating (FBG) sensors. The mode decomposition method was employed to analyze the measured strain signals. The dominant frequency, displacement traces, standard deviation of displacements and fatigue life associated with the in-line vibration were obtained. The experimental results indicted that the higher order response mode from the in-line vibration together with the large deflection may reduce the fatigue life of risers as severely as that from the cross-flow vibration, which should be paid much more attentions to the practical engineering applications.

KEY WORDS: vortex-induced vibration; in-line dynamic response; long flexible risers; laboratory tests; fatigue life.

INTRODUCTION

Many flexible slender structures in offshore engineering, such as deepwater risers, TLP tendons and hanging cables are subjected to marine currents. As the fluid flow passes these cylindrical structures, the well-known vortex shedding is observed, resulting in the fluctuating forces on the structures and finally inducing the vibrations of structures in both cross-flow and in-line directions, This phenomenon is commonly called as vortex-induced vibration (Gabbai and Benaroya, 2005).

The vast research efforts have been focused on understanding and predicting the dynamic response of vortex-induced vibration by means of experimental and numerical approaches. Contrasted to the extensive investigations on the cross-flow response of the long flexible risers, the in-line dynamic response has received little attentions so far due to its rather smaller oscillating amplitude (Søreide, 2002). However, the in-line response frequency is generally two times of the cross-flow and bears the inherent non-linear characteristic of the vibrating system (Vandiver, 1993). Hence, the dynamic response of in-line may be also as important as the cross-flow, especially for its contribution to the fatigue damage (Søreide, 2003). Furthermore, the complicated interactions between the fluid flow and structures involve indeed both cross-flow and in-line. It means that the in-line response due to VIV must be considered seriously for practical applications.

In this work, the laboratory test results with special attentions to the in-line dynamic characteristics of a large aspect-ratio flexible riser model under vortex-induced vibration are presented. This paper is organized as follows. The experimental set-up is described firstly. Then the corresponding experimental results are presented. The dominant frequency, displacement traces, mean and maximum Root Mean Squared displacements and fatigue life will be addressed. Finally, some conclusions are drawn.

Description of Experimental Setup

The experiment was conducted in a wave basin at the State Key Laboratory of Coastal and Offshore Engineering (SLCOE), Dalian University of Technology (DUT). The wave basin is 34 m in width and 55 m in length. The total depth of water in the experiment is 0.7 m. The average position of the riser model was 0.4 m below the water surface and 0.3 m above the bottom of the wave basin. The riser model to be tested was suspended at a towing car with universal joints. By means of towing the riser model in the wave basin, the uniform current speeds ranging from 0.15 m/s to 0.60 m/s were generated giving the Reynolds Number from 2400.0 to 9600.0. The overall layout of the experimental setup is shown in Fig.1, Fig.2 and Fig.3

A spring-tension system was designed at the end of the riser model allowed to supply the pre-tension. The stiffness of spring is 6900 N/m. A load cell was employed to monitor the tension due to the deflection and vibration of riser model.

The material of the riser model is homogeneous flexible steel pipe. During the laboratory tests, the riser model was filled with air, giving the mass ratio $m^* = 4m / \rho\pi D^2$ to be 1.0, where m is the mass of riser model (noting that, the added mass is not included here) of per unit length. ρ is the density of fluid. The detailed properties of the riser