Experimental Investigation on VIV Responses of a Long Flexible Riser Towed Horizontally in a Wave Basin

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ABSTRACT

This paper reports experimental tests on vortex-induced vibration (VIV) of a long flexible riser towed horizontally in a wave basin. The riser model has an external diameter of 16 mm and a total length of 28.04 m, giving an aspect ratio of about 1750. Reynolds numbers are within the range from $10^3$ to $10^4$. The mass ratio of the riser model is 1.0. Fiber optic grating strain gauges are used to measure the dynamic response of the model. The VIV response strain, vibration frequency and amplitude, displacement, and displacement standard deviation of the flexible riser model were examined in both cross-flow and in-line directions. The experimental results showed that the cross-flow dominant mode may reach up to 6 and the in-line dominant mode over 12 with dominant frequencies given by a Strouhal number of about 0.18. Higher harmonics such as the third, fourth and fifth vibration components were also observed.

KEY WORDS: experimental tests; vortex-induced vibration; long flexible riser; cross flow motion; in-line motion; high mode.

INTRODUCTION

Vortex-induced vibration (VIV) of offshore structures subjected to ocean currents is a widely occurring phenomenon in offshore engineering, which may cause large fatigue damage. Despite the large number of documents dedicated to the problem of elastically mounted rigid cylinders with one or two degrees of freedom, there are only a few experimental studies on VIV of a long flexible pipe, especially those involving high mode numbers. Some studies concentrate on VIV of a flexible cylinder like Vandiver (1993), Lie et al. (1998), Park et al. (2004), and Song et al. (2009). However, the aspect ratios in these studies are not large. For exploration in ultra deep waters, the lengths of flexible risers are more than 2000 m with aspect ratios of order $10^3$. Several investigators such as Huse et al. (1998), Trim et al. (2005), Vandiver et al. (2005), and Vandiver et al. (2006), have conducted experiments with aspect ratios of more than 1000 to study VIV of long flexible cylinders.

Huse et al. (1998) presented the results of the Hangøytangen tests, which were conducted alongside a quay in Hangøytangen, Norway. The length of the steel pipe was 90 m and the diameter was 3 cm. The current condition was linearly varying sheared flow. They provided both bending stiffness controlled natural frequencies as well as tension dominated natural frequencies.

Trim et al. (2005) presented an experiment of a 38 m flexible pipe with a diameter of 2.7 cm. The tests were carried out in both uniform and linear shear flows and excited up to the 16th mode for the dominant cross-flow VIV. Although this experiment was well designed, it may suffer from the instrumentation of strain gauges and accelerometers since they were installed on the outside of the pipe, which may change the diameter and mass at the local sections.

Vandiver et al. (2005) reported the Lake Seneca tests, in which a 122.2 m pipe with a 3.3 cm diameter was used. Subsequently, the Gulf Stream Tests were also conducted (Vandiver et al., 2006) employing a 152.5 m circular cylinder with a 3.6 cm diameter. Both the Lake Seneca tests and the Gulf Stream Tests were field measurements with complex current profile conditions, which might be a limitation in understanding the VIV response. It was noted (Chaplin et al., 2005) that the field measurements can provide some overall indications of the accuracy of predicted displacements, curvatures and frequencies, but in general they are characterized by inadequate documentation of the ambient conditions especially the profile of the incoming flow, and by sparse instrumentation and instrument failures.

The present paper describes a laboratory experiment on VIV responses of a long flexible riser with a large aspect ratio of 1750. The long riser model is exposed to a uniform flow of up to 0.60 m/s over all its length. And the mass ratio is designed to be 1.0. A new measurement technique of fiber optic strain gauge is employed. Measurements are obtained of the riser’s response to vortex excitation at high modes in both cross flow and in-line directions. Tension variation, strain amplitude and response frequency, modal weights of the excited modes, dominant mode and frequency, displacement response are analyzed.

EXPERIMENTAL SET-UP

The experiments were carried out in a wave basin at the State Key...