Experimental Study on Vortex-Induced Vibration of a Long Flexible Pipe in Sheared Flows

Sup Hong, Jong-Su Choi, Hyung-Woo Kim, Tae-kyeong Yeu, Jin-Ha Kim, Young-Sik Kim and Seong-Gil Kang
Maritime and Ocean Engineering Research Institute
Daejeon, Korea

Chang-Kyu Rheem
Institute of Industrial Science, University of Tokyo
Tokyo, Japan

ABSTRACT

Experiments on vortex-induced vibration of a long pipe model (L/D = 400) were conducted in linearly sheared flows. The top flow speed was varied from 0.2m/sec to 2.0m/sec in step of 0.1m/sec. A fiber glass pipe was instrumented with FBG (Fiber Bragg Grating) sensors to measure the strains in VIV responses. The number of strain measurement stations was 15 for each fiber with spacing of 1m. Initial pipe tension was varied as 80kgf, 90kgf and 100kgf. The modal analysis of strain measurement data was conducted. The peak VIV frequency coincides with the Strouhal frequency corresponding to 70% of the maximum flow speed. The mode number of the maximum amplitude vibration is determined by the integer ratio of the peak vibration frequency to the natural frequency of the model. The main vibration mode is caused by the VIV mode corresponding to the flow speed at the mid region of the model. There exist traveling waves in high flow speed region and standing waves in low speed region. The VIV response in linearly sheared flow is multi-mode.

KEY WORDS: VIV (vortex-induced vibration); long flexible pipe; linearly sheared flow; modal Analysis; lock-in; multi-mode response.

INTRODUCTION

Vortex-induced vibration of slender marine structures such as marine risers, pipelines and cables is the critical factor determining the structures fatigue life. Vortex-induced vibration (VIV) is caused by alternating shedding of vortices from either sides of the structure. The dissipated kinetic energy of the flow due to vortex shedding provokes lift forces and structure vibration in vortex shedding frequency \( f_v \) determined by Strouhal relation. The vibration component of \( f_v \) occurs in the cross-flow (CF) direction. The CF vibration is coupled with the in-line (IL) vibration, whose frequency is doubled to be \( 2f_v \). Depending on phase angle between CF and IL displacements, the vibration trajectory of a point in structure results in crescent shape or figure eight. If the vortex shedding frequency approaches to the natural frequency \( f_n \) of structure, a resonance phenomenon (so called, lock-in) happens, where the vortices are shed in the vibration frequency.

The phenomenon of VIV has been extensively tackled in numerous studies. Blevins (1990) presents fundamental understandings on various flow-induced vibrations including VIV subjects. Reviews on recent VIV studies are found in Williamson and Govardhan (2004).

For deep water application of slender structures, Vandiver (1993) described the dimensionless parameters, which are important to the prediction of VIV of long, flexible cylinders in ocean currents.

In case of long slender structures, high mode number response is resulted from structure elasticity. Recently, the multi-mode responses in VIV of long marine structures have been experimentally investigated in model basins and fields.

For some instances, Trim et al. (2005) performed model tests with L/D = 1400 in uniform and linear shear flows and showed that not only CF mode but also IL mode has to be considered for prediction of fatigue damage. Lie and Kaasen (2006) conducted modal analysis of the measurement results from a large-scale model test (L/D = 3000) in linearly sheared flow. They showed that as a consequence of non-uniform current profile the VIV responses are highly irregular and the degree of irregularity increases with the flow speed. Vandiver et al. (2009) analyzed the measurement data from field experiments with a long cylinder (L/D = 4200). They revealed that traveling wave VIV is dominant at high mode numbers. In tension dominated cylinder, the IL and CF wave components travel at the same speed. Thus traveling wave VIV excitation was favored.

This paper presents the modal investigation of VIV response measurements of long, flexible pipe model in linearly sheared flows, resulted from the model tests at MOERI in 2007. Fiber optic sensors were used for strain measurement. Frequency analysis was conducted for bending moments. Using modal analysis the VIV mode responses were investigated, and the shape vectors at each measurement positions, i.e. the average fluctuation distributions including phases were obtained.