Fatigue Damage of Risers with Two-Degrees-of-Freedom Vortex-Induced-Vibration

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ABSTRACT

The more practical case of vortex-induced vibration in two degrees of freedom has been presented. The mass ratio is low and equal to $m^*=1.78$. The response amplitude showed three branches namely, the initial branch, the super-upper branch and the lower branch. The reason for the appearance of the super-upper branch is owed to the power increase. The fatigue damage in two degrees of freedom has been compared with that in one degree of freedom. The results showed the in-line fatigue damage can not be neglected especially in the initial branch and the super-upper branch. The in-line fatigue damage could be a main contributor under low reduced velocity and distinctly have a positive influence on that in cross-flow direction in the super-upper branch.

KEY WORDS: risers, vortex-induced vibration, fatigue damage, mass ratio, two-degrees-of-freedom

INTRODUCTION

The problems of vortex-induced vibration (VIV) have been paid more attention in recent years due to the demand of petroleum industry moving towards deep water. Many efforts have been devoted to the prediction of VIV of deepwater marine risers and free span pipelines response mainly in the cross-flow direction for structural design according to the fatigue damage criterion.

Vandiver (1987) discovered that there was an interaction between in-line vibration and cross-flow VIV that showed as a chart of ‘eight-of-figure’. Moe and Wu (1990) carried out two studies for systems enabling $x$-$y$ motion of a cylinder, the mass ratios in the $x$ and $y$ directions were quite different, and also the natural frequencies were set in the ratio $f_x/f_y=2.18$. Under these special conditions, they found a broad regime of reduced velocity $U_n$ (where $U_n = U/f_x D$, $U =$ free-stream velocity, $f_x =$ natural frequency; $D =$ diameter) over which resonant amplitudes were found (with transverse normalised amplitude close to $A_x/D =1$, $A_x$ is the response amplitude in cross flow direction), but without any evidence of distinct response branches. For their $x$-$y$ experiments, Moe and Wu (1990) found that the position of maximum response shifted to rather higher values of $U_n$ and reached slightly higher amplitudes, as compared with $y$-motion experiments. Jautis and Williamson (2003;2004) set an experiment which the mass and natural frequencies were precisely the same in both $x$ and $y$ directions with a light body $m^*$ ($m^* =$ mass of oscillating structure/displaced fluid mass) $< 6$. They found even down to the low mass ratios, where $m^* = 6$, it is remarkable that the freedom to in-line oscillation, affects the transverse vibration surprisingly little. There was, however, a dramatic change in the fluid–structure interactions when mass ratios were reduced below $m^* = 6$. A new amplitude response branch with significant transverse motion happened, that being called the “super-upper” branch, yielding massive amplitudes $A_y/D=1.5$. Sanchis (2008) and Dahl (2006) found this phenomena when considering different frequency ratios and Huang and Pan (2007) found the critical mass ratio $m^*=3.5$. However, based on the previous research, the importance of the in-line vibration has been found and few papers have devoted to study the fatigue damage caused by the in-line vibration.

In this paper, a numerical method is used to predict the two-degree-of-freedom motions of a top tensioned riser with a mass ratio $m^*=1.78$ and with long aspect ratio ($L/D=$length of riser/ external diameter of riser) $L/D=4631$. Here, we find the “super-upper” branch in a narrow regime of velocity $U_n$ and there will be an increase of the power of the displacement when the response amplitude presents a “super-upper” branch. The results are compared with Jautis and Williamson (2004). Also, this paper presents the fatigue damage induced by the in-line vibration and cross-flow vibration with different response amplitude branch.

DYNAMIC ANALYSIS

Global Response

It is assumed that the current flow is in the $x$ direction, and the cross-section of riser is uniform. The coordinate original point is at the bottom of seas. The structure model is illustrated in Fig 1. The current is uniform.

![Fig 1 Coordinate system and model](image-url)