Dynamic Effect of Internal Flow on Curved Pipe

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ABSTRACT

Numerical study about the dynamic effect of internal progressive flow on a flexible riser model deformed by external shear current has been carried out. The CAE technology which combines ANSYS structural analysis software with a CFD program (CFX) has been proposed to solve this FSI problem. It has been found that the existence of internal flow does play an important role in determining the vibration mode, vibration intensity and the magnitude of instantaneous vibration amplitude of the curved riser model, when velocity ratio of internal flow against external current is relatively high.

KEY WORDS: dynamic effect; internal flow; flexible riser; shear current; fluid-structure interaction, CFD.

INTRODUCTION

In the field of ocean engineering, practical significance of vortex-induced vibration has led to a large number of fundamental studies. There are so many works carried out for VIV research relating flexible riser systems subject to various kinds of external current, e.g. uniform, shear or even nonlinear-patterned, and a great deal of work has been done on the dynamics of straight pipes conveying fluid over the past 60 years or so. However, relatively less effort has been directed towards the investigation of the fluid-structure interaction (FSI) dynamics and stability of fluid-conveying curved pipes or risers. In fact, flexible riser or piping may be curved into complex spatial forms, when they are deformed. In this paper, the dynamic effect of internal flow combining with external shear current on a flexible riser model will be considered. It may cause the happening of multi-modal coexistence or even the emergence of vibration modal transition subsequently. As a result, the riser vibration might be ‘locked-in’ within a special reduced velocity range in which large deflection or high vibration modes may be excited (Lopes and Paidoussis, 2002; Semler and Lopes, 2002). This may consequently lead to structure failure of marine riser system prematurely.

The dynamics and stability of curved pipes in the form of circular arcs were studied extensively by Chen (1972a; 1972b; 1973). He derived the equations governing in-plane motions using both the Newtonian (Chen, 1972a) and Hamiltonian (Chen, 1972b) formulations, and equations governing out-of-plane motions from the Hamiltonian viewpoint. It was found that in the case of clamped-clamped and pinned-pinned boundary conditions, the pipe loses stability by divergence when the flow velocity or the fluid pressure exceeds a certain critical value. This behavior is qualitatively similar to that of a straight pipe. Chen also studied the stability of cantilevered curved pipes. He found that for in-plane motions such pipes are generally subject to both divergence and flutter instabilities, with divergence occurring first, except in cases where the subtended angle is very small (so that the system comes closer to a straight pipe), when only flutter was found to arise. A thorough study about the equations of motion was undertaken by Dupuis and Rousselet (1992), who concluded that the stressed-by-flow configuration is the only equilibrium state adequate for the study of the linear stability of such pipe-fluid systems. Recently, Karagiozisa and Paidoussis (2007) have studied the nonlinear stability of circular cylindrical shells which are subjected to internal flow, by means of the Donnell nonlinear shallow shell equations and a linear fluid–structure interaction model. They have found that the riser model system loses stability by a subcritical pitchfork bifurcation, leading to a stable divergence of increasing amplitude with flow.

In those previous studies, much attention has been focused on the dynamic effect of internal flow on straight and curved pipe solitarily, and other associated dynamics had rarely been considered. It is worth noting that the external current is the main factor to cause flexible riser deformed. In this paper, the dynamic effect of internal flow combining with external shear current on a flexible riser model will be considered. As it is well known, in the case of non-uniform external current being imposed, the progressive direction of internal flow and the corresponding influence on FSI response of flexible riser systems should be paid much attention. There are two kinds of progressive directions in general, which are opposite to each other for the flow progressing inside riser/pipe structure. An end may be regarded as inlet in some situations, but may be regarded as outlet in others. On the other hand, piping may be curved into complex spatial forms, e.g., asymmetrical span. Comparing to the vibration response of straight pipes conveying fluid, the dynamics and stability of fluid-conveying curved pipes is much more worth focusing on (Paidoussis, 1998). The emergence of asymmetrical vibration response along riser span usually attributes much to the diversity of structural assembly (e.g., two ends being not equally restrained), and the variety of dynamic loading on riser system (e.g., the external current pattern being of non-uniform patterned). As a result, it aggravates the deformation behavior which is attributed to centrifugal and Coriolis accelerations in some ways.