Numerical Study of Vortex-Induced Vibration for Flexible Riser and Pipe Models

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ABSTRACT
This paper summarizes the VIV-related research with the focus on flexible riser and pipe models subject to various engineering conditions. First of all, a series of numerical simulations for the purpose of validating the efficiency of FSI solution approach (ANSYS MFX) has been performed. The comparison between the simulation and the experimental data shows that the present FSI solution method is capable of giving acceptable estimation to VIV problems. As a meaningful application to engineering problems, some tentative simulation cases which are difficult to carry out in experiment, such as a flexible pipe with internal flow and multi-assembled pipes, have been successfully carried out. The coupling mechanism between vortex shedding and the VIV has been well interpreted.

KEY WORDS: Vortex-induced vibration (VIV); riser; internal flow; forced motion; multi-assembled pipes; FSI.

INTRODUCTION
Flow around a fixed or oscillating cylinder has received much attention in the past few decades. Since the current and wave propagates with high degree of complexity, the flexible risers/pipes are readily subjected to shear or oscillatory flow in real ocean conditions. As is well known, vortex-induced vibration plays a leading role in determining the life span of marine risers. Due to the developing deepwater oil exploitation and massive use of underwater cables, the need to enhance our knowledge about vortex-induced vibration (VIV) for elastic pipe has greatly risen. A better comprehension of the vortex dynamics causing vibration and fatigue to risers is necessary.

The fact that numerical simulations of VIV have been failing to accurately duplicate experimental processes mostly attributes to the complexity of the physics involved in the real problem. It is worth noting that the separation excursions and the coupling mechanism between the vortex wake and the dynamics of the structure are the key factors. From the multi-physics point of view, fluid-structure interaction (FSI) occurs when fluid interacts with a solid structure, exerting pressure to the structure. As a result, it leads to deformation of the flexible structure, and then alters the flow conformation finally. Due to the limitation of calculation ability and some shortages of CFD software package itself, most numerical attempts are apt to 2D vortex simulations and then integrate the hydrodynamic forces to 3D fluid domain (Yamamotoa, Meneghiniib et al., 2004). Some tasks to simulate vortex-induced vibration with considerably large aspect ratio are indeed a 2D numerical simulation (Holmes, Owen et al., 2006).

Grid topology and density, boundary condition, and coupling scheme between the flow governing equations and structure motion equations have strong influence on the qualities of the numerical results (Holmes, Owen, 2006). With risers presenting comparatively high aspect ratio and complex flow field around them, a complete three-dimensional simulation close to realistic conditions should be looked for. Aiming at an acceptable hydro-elastic response of the riser structure, a more robust numerical strategy should be introduced. Rapid development of commercial CFD software provides us some new choices for FSI numerical simulation. Menter has successfully simulated two kinds of FSI cases using ANSYS multi-physics software (Menter and Sharkey, 2006). It preliminarily verified the capability of MFX solver to deal with coupling fluid-structure problem.

By means of ANSYS MFX solution approach and 3D large eddy simulation model, the FSI problems related to several engineering condition have been solved in this paper. The efficiency validation of MFX solver has been performed first to evaluate the performance of this FSI software. Some tentative simulation cases closely related to ocean engineering has also been carried out. The main purpose of those simulations is to provide supplementary information on vortex wake for the model test and carry out advanced research on VIV before actual engineering applications.

NUMERICAL SOLUTION

FSI strategy of ANSYS
ANSYS MFX solver has been adopted to solve the FSI problems related to VIV of flexible risers/pipes in this paper. The well-designed ANSYS FSI solution strategy provides tightly integrated flow and structure physics. It offers designers and analysts a most flexible and advanced coupled structure–fluid physics analysis tool. In addition, the adoption of the implicit coupling iteration ensures that fluid and structure solution fields are consistent with each other at the end of each multi-field step. It leads to improved numerical solution stability (ANSYS, 2007).

Turbulence model
Generally speaking, the discrepancy between experiments and numerical simulations partially attributes to the disability of turbulence model and the time-space resolution of the grids used in numerical simulation. Since the Reynolds numbers of all the simulation cases in this paper are relatively low, the LES model has been adopted for accurate prediction of vortex shedding.

EFFICIENCY VALIDATION OF FSI SOLUTION
Before applying the ANSYS MFX scheme to solve the VIV problem,