Numerical Investigation of Vortex Induced Motion of a Square Cylinder at Low Reynolds Numbers

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ABSTRACT

Vortex induced motion (VIM) can occur on any bluff body (such as buoys, FPSOs, semi-submersibles, Spars and TLPs) exposed to current. VIM is well-acknowledged to have a strong impact on the fatigue life of mooring and riser systems and must be quantified and sometimes mitigated. As part of the effort to numerically investigate VIM response of multi-columns floating platform, we start with the fundamental study of VIM around a square column at low Reynolds numbers (Re), seeking to investigate and accurately simulate the dynamic processes of vortex shedding, transportation and wake interactions with the bluff body and its motion in response. OpenFOAM, an open source CFD toolbox, is used to solve the transient flow pattern around a stationary and free moving square cylinder. A rigorous benchmark of the present simulation against experiments and numerical simulations is demonstrated for both stationary and free moving square cylinders at 60 ≤ Re ≤ 200. The cylinder, with a blockage area of 5%, is mounted on elastic supports for free vibration in both in-line and transverse directions. The effects of grid types and resolutions on the key features of vortex dynamics, vortex induced motion, and the stability of dynamic mesh solver in OpenFOAM are explored. It is found that hybrid unstructured grid has better performance and stability than structured-O grid in OpenFOAM dynamic solver. The effects of mass ratio, spring stiffness and damping on the motion of square cylinder are discussed. It is observed that the phase angle difference between lift coefficient and transverse amplitude of the cylinder is correlated with mass ratio, spring damping and Reynolds number. An abrupt jump of phase angle difference between lift coefficient and transverse amplitude occurs at Re=76 with mass ratio of 25. The damping effect plays a significant role in the phase angle difference between lift coefficient and transverse amplitude of the cylinder.

KEY WORDS: Vortex-induced motion; square cylinder; vortex shedding.

INTRODUCTION

In the recent years, vortex-induced motion (VIM) of semi-submersible or floating platforms with square columns in offshore engineering raise much attention in many aspects of structure stability, fatigue of riser and mooring line and operations, as a number of deep-draft installations were found to be delayed in Gulf of Mexico with strong current environment. An offshore floating platform is a complex system, having umbilical mooring lines, production risers and equipment that are connected to the main hull; and as such, its vortex-induced motion (VIM) could comprise up to the full six degrees of freedom complexity. The dimension, geometric arrangement of the platform, draft condition, current velocity, lines-induced damping and water depth are key factors to trigger VIM. A good overview on these relevant aspects of VIM of floating platform can be found in the paper of Concalves et al. (2012). Briefly, major concerns of VIM often focus on the in-line (surge) and the transverse (sway) motion of floaters. The importance of yaw motion of the platform was highlighted by Waals et al. (2007). A comprehensive experimental study of VIM of semi-submersible platform with four square columns under the effects of current and waves was conducted by Concalves et al (2012,2013). In their findings, periodic motion of platform by VIM under sea state tests are observed but the amplitude of semi-submersible platform is lower than that of current-only tests. The current has a dominant effect on VIM phenomena, whereas, the current-wave interactions are found to have mitigated VIM of the platform.

The present study is a part of numerical effort to comprehensively investigate VIM response of multi-columns floating platform, and as a start, we first focus on the fundamental and essential study of vortex-induced motion (VIM) around a square column at low Reynolds numbers. In this study, we seek to investigate and accurately simulate the dynamic processes of vortex shedding, transportation and wake interactions with the bluff body and its motion in response. From literature survey, very few studies were found to be published on square cylinder’s VIV as compared to circular cylinder’s VIV, with a few studies cited here. For experimental reports of VIV on a square cylinder, Bearman et al. (1982) conducted an experimental measurement of fluctuating forces on a square cylinder at 0° flow incidence in a wind tunnel. Cheng et al. (2003) investigated the transverse vibration of a square cylinder at Re=3500 in a wind tunnel. More recently, Amandolese and Hemon (2010) carried out an experiment of a transversely vibrating square cylinder in a wind tunnel at Re=2000-8000. A large mass ratio of 905 was used with reduced velocity between 5 and 20. In the limit cycle regime, the cylinder amplitude’s behavior with reduced velocity and vibrating frequency of the cylinder was discussed in detail. Zhao et al. (2010) studied two types of cylinders (square and diamond) in a water flow at a low mass.