Fluid Forces and Structure-Induced Damping of Obliquely-Oscillating Offshore Structures

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ABSTRACT

We use high-order CFD methods and statistical analysis techniques to study the flow over a cylinder, approximating circular cross-section offshore structures, oscillating in a direction inclined to the horizontal direction. We vary the orientation angle from 0 to 180 degrees, where the 90-degree case corresponds to oscillation perpendicular to the incoming stream. We study (in the time-domain and through the angle-response curves) variations of the induced force properties, their symmetry or skew symmetry about the case of a 90-degree orientation angle, and the structure-induced damping of the flow. We identify the range of orientation angles where the entrainment phenomenon takes place and study the influence of the motion amplitude on this phenomenon. We propose a technique to derive reference (scaling) quantities for the oblique fluid force. Unlike the lift and drag, such reference quantities cannot be obtained from the stationary-structure case because such an oblique force is not defined then.

KEY WORDS: offshore; cylinder; flow; oscillation, entrainment; damping, excitation

INTRODUCTION

Fixed platforms, tension-leg platforms, spars, offshore wind turbines, and chimneys share a rigid circular cross-section element. Several studies have investigated the flow over stationary and moving cylinders and cables, and the fluid-structure interaction (FSI) associated with the latter two cases. Different cross-sections have been considered, including circular, elliptic, and square ones. In addition, for two-dimensional moving-structure cases, different motion orientations have been also considered. These include 1 DOF perpendicular to the incoming flow stream (Carberry et al., 2001; Marzouk and Nayfeh, 2008), 1 DOF parallel to the incoming flow (Kim and Williams, 2006; Guilmineau and Queutey, 2004), and both 2 DOFs (Jauvtis and Williamson, 2003). There have been studies that even explored angular oscillations of the structure instead of the translational one (Baek and Lee, 2001).

We here examine the influence of tilting an oscillating cylinder from the vertical direction (the incoming stream sets the horizontal direction), with both clockwise and counterclockwise angles, on the induced hydrodynamic force on the cylinder at different amplitudes of oscillation. The vertical-oscillation case has been a focus of attention for decades, and no studies attempted to consider the oblique-oscillation scenarios as we are doing here. The orientation angle can be perceived as an angle of attack of the incoming stream against the vertically-oscillating cylinder. We show that some flow properties vary symmetrically about the vertical-oscillation case, whereas others exhibit skew-symmetric variation about it. We also show how changing the orientation angle of oscillation can invert the sign of the structural-induced damping of the flow in the wake. For the same oscillation frequency and amplitude, the oscillation may excite the flow (negative structure-induced damping of the flow) resulting in intensified hydrodynamic force; or it may dampen the flow (positive structure-induced damping), resulting in an attenuated hydrodynamic force. We study the relationship between this structural damping and the orientation angle of oscillation. In addition to the classical lift-drag decomposition of the hydrodynamic force, we compute an additional oblique component, which is important in this study since it is the effective force that determines whether the structural oscillation excites or dampens the flow and determines the direction of mechanical energy transfer between the fluid and the structure.

It is a well-known phenomenon that when a uniform stream flows past a bluff-shaped structure (this extends the scope of this study beyond smooth cylinder-like structures to those equipped with some fairings), then a regular vortex-shedding pattern occurs in the wake with a nondimensional Kármán frequency that is almost 0.2 for a very wide range of Re in the subcritical regime (Re = $300 - 2 \times 10^5$). If this frequency is close a structural natural frequency, then a resonating hydrodynamic force causes structural fatigue that may eventually lead to damage. If the structure is moving freely or forcedly with an oscillatory pattern (or the incoming stream has an oscillatory vertical velocity component) with a frequency that is close to the Kármán frequency, then the shedding frequency is entrained by the structural frequency. While previous studies examined the influence of the oscillation amplitude (relative to the structural hydraulic diameter) and its frequency (relative to the natural shedding frequency) on this phenomenon, we add a third dimension to this problem, which is the