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Numerical Investigation of Vortex-Induced Vibrations of an elastically-mounted Circular Cylinder Beneath a Free Surface: Modes & Frequencies

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ABSTRACT: In this paper, a two-dimensional numerical simulation is applied to study the Vortex-Induced Vibrations (VIV) of an elastically mounted rigid circular cylinder beneath a free surface of fluid. The effect of free surface in laminar flow (60 < Re < 130) with Fr=0.2 is investigated with considering two Gap-Ratios of 2.5, 1.5. The natural structural frequency of oscillator is assumed to match the vortex shedding frequency for a stationary cylinder at Re=100. Simulations of VIV and Free Surface of fluid flow have separately shown good agreement with previous results. User Defined Function (UDF) hooked in the Software is given to couple the motion of cylinder to flow motion. For simulation of free surface, Volume of fluid (VOF) method is used. This paper is the second part of an investigation about effects of Free Surface of fluid on VIV phenomena. The effects of Free Surface is investigated with using a comparison of vortex shedding modes and non-dimensional frequency diagrams for the two Gap-Ratios. With approaching cylinder to free surface, results shows changing type of vortex shedding modes, abatement in lock-in region, increasing Strouhal number and non-dimensional frequency ratio.

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1. Introduction

Vortex-Induced Vibration (VIV) is a fundamental phenomenon frequently encountered in many practical engineering applications and physical sciences where an external fluid flow dynamically excites and interacts with a freely mounted bluff solid or flexible structure. The unsteady flow force, generated by the alternate vortex shedding, affects the structural vibration, while the oscillating structure will in turn influence the flow field, giving rise to a complex nonlinear coupled fluid–structure interaction problem. Numerous authors have investigated VIV of freely suspended cylinders since the pioneering work of Feng [1]. For example, Mittal and Kumar [2] employed a stabilized space-time finite-element method to investigate the two dimensional vortex induced vibrations of a light circular cylinder, mounted on lightly damped flexible supports, and free to move in cross-flow and in-line directions at low Reynolds numbers. Also Prasanth and Mittal [3] used a 2D stabilized Finite-Element Method (FEM) to investigate free vibrations of a circular cylinder of low mass ratio in laminar flow.

The interaction of a free surface wave motion with moving cylindrical bodies has been principally the subject of some recent studies. In a sample work, Bozkaya and Kocabiyik [4] used a numerical solution of the special integral form of two-dimensional continuity and unsteady Navier–Stokes equations to investigate vortex states of a horizontal cylinder undergoing forced oscillations in free surface water wave, Their study aims to examine the consequence of degree of submergence of the cylinder beneath free surface at Froude number 0.4, Calculations are carried out for a single set of oscillation parameters at a Reynolds number of *Re*=200.

The entire review clearly indicates, the two-degree-of-freedom VIV of an elastically supported circular cylinder beneath a free surface has not been studied. This paper is a continuation of previous authors' research [5] from the perspective of the modes and frequencies. The purpose of this research is investigation of the effect of free surface of fluid on the phenomenon of VIV particularly Lock-in region.

2. Methodology and Validation

The simulation consisted of two parts: 1) simulation of VIV in an unlimited fluid, 2) fluid flow simulation around a fixed cylinder near the Free Surface.

2.1 Simulation of vortex-induced vibration in an unlimited fluid

In present study, the fluid is assumed to be Newtonian and incompressible, governed by the Navier–Stokes equations:

$$\frac{\partial u_i}{\partial x_i} = 0 \tag{1}$$

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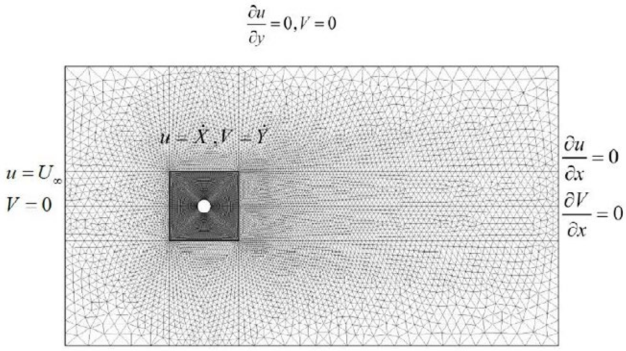

Fig. 1 Grid topology for Vortex induced vibration simulation and its Boundary condition

$$\frac{\partial(\rho u_i)}{\partial t}+\frac{\partial(\rho u_j u_i)}{\partial x_i}=-\frac{\partial p}{\partial x_i}+\mu(\frac{\partial^2 u_i}{\partial x_j \partial x_j})+\rho g_i \tag{2}$$

A simple schematic of the flow configuration of the rigid circular cylinder (With its grid and boundary condition), mounted on an elastic base with two degrees of freedom is shown in Fig. 1.

The elastic cylinder may be modeled by a simple mass-damper-spring system of stiffness with the following non-dimensional equations of motion:

$$\ddot{X}+4\pi F_N \zeta \dot{X}+(2\pi F_N)^2 X=\frac{2C_D}{\pi m^*} \tag{3}$$

$$\ddot{Y}+4\pi F_N \zeta \dot{Y}+(2\pi F_N)^2 Y=\frac{2C_L}{\pi m^*} \tag{4}$$

In every time step of the interaction process, the governing Eqs. (1) and (2) are solved by using the commercial Computational Fluid Dynamics (CFD) code ANSYS Fluent 14.0, a finite volume solver. For more information about this section, Please refer to Hosseinalipoor and Hajighafoori boukani [5].

2.2 Fluid flow simulation around a fixed cylinder near the Free Surface

For this section, Please refer to Hosseinalipoor and Hajighafoori boukani [6].

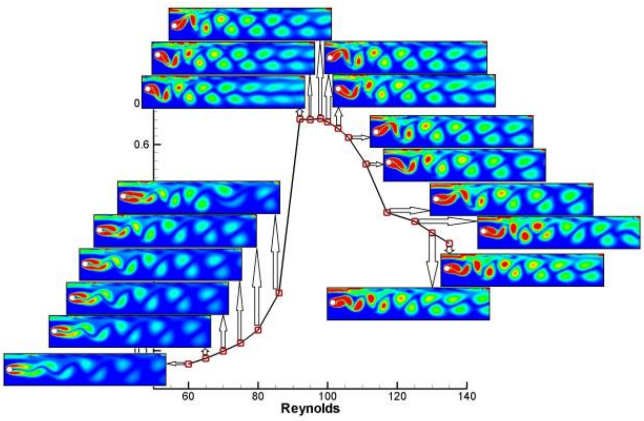

Fig. 2 Modes of vortex shedding for gap-ratio=2.5 depicted on transverse displacement response amplitudes

The effect of free surface in laminar flow is investigated with considering two Gap-Ratios. The natural structural frequency of oscillator is assumed to match the vortex shedding frequency for a stationary cylinder at Re=100 (Fr = 0.2, 60 < Re < 150).

3. Results and Discussion

Fig. 2 shows modes of vortex shedding for gap-ratio=2.5 which depicted on transverse displacement response amplitudes [5]. In the range of Reynolds numbers 60 to 86 or the initial branch, the vortex mode is 2S. While in some of the larger Reynolds, we are seeing C(2S) mode.

Fig. 3 shows changes in the Strouhal number of the flow around the cylinder for gap-ratio=2.5 and 1.5 versus Reynolds number. The free surface causes an increase in the Strouhal number and in the non-dimensional frequency ratio (Fig. 4). In the initial branch, from Reynolds number 60 to 80 for both gap-ratios, the frequency of vortex shedding for the fixed and oscillating cylinders is the same. In Reynolds 80, a sudden jump occurs in the Strouhal number, this jump is the same jump for the Synchronization.

Fig. 4 shows frequency ratio of the vortex shedding (for the VIV cylinder to the normal frequency of the system) for gap-ratio=2.5 and 1.5 versus Reynolds number. In the lock-in area, the free surface does not have much effect on the frequency ratio diagram. In the initial branch, the frequency of the vortices is less than the normal frequency of the system and in the upper branch is more than the normal frequency of the system. At the end of the upper branch, the frequency of the vortices is jumped to the amount for the fixed cylinder. The first transition is from the initial branch to the upper and it is related to the jump at the frequency of the vortex shedding.

4. Conclusions

In this paper, the vibrations caused by vortex shedding flow around a cylinder near the free surface of the fluid was examined. The survey showed that Lock-in region area can be controlled by adding a specific free surface.

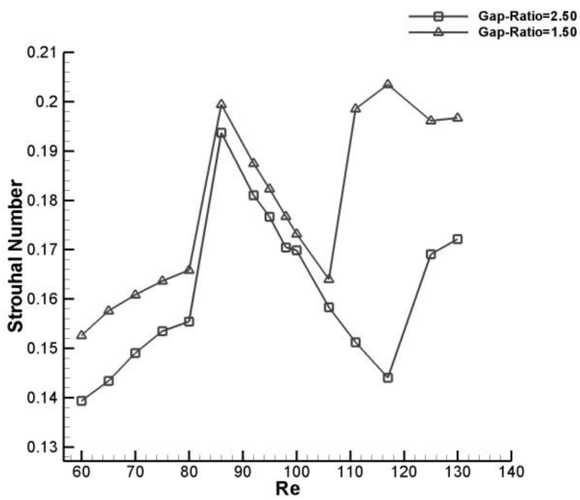

Fig. 3 Changes in the Strouhal number of the flow around the cylinder for gap-ratio=2.5 and 1.5 vs. Reynolds number

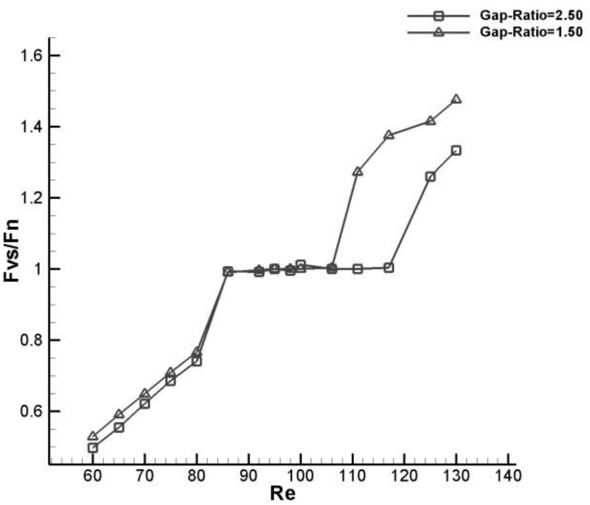

Fig. 4 Frequency ratio of the vortex shedding from the vibrating cylinder to the normal frequency of the system for gap-ratio=2.5 and 1.5 vs. Reynolds number

Here is some results: In the lock-in area, the free surface does not have much effect on the frequency ratio diagram. Modes of vortex shedding are different ($2S$, $C(2S)$) in different branches of the response. The free surface causes an increase in the Strouhal number and in the non-dimensional frequency ratio.

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