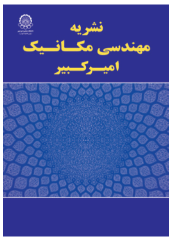

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Numerical Investigation of Vortex-Induced Vibrations of an Elastically-Mounted Circular Cylinder beneath a Free Surface

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ABSTRACT: In this paper, a two-dimensional numerical simulation is applied to study the vortex-induced vibrations of an elastically mounted rigid circular cylinder beneath a free surface of fluid. 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. Discretization of flow equations based on the Finite Volume method was implemented in computational fluid dynamics commercial software Ansys Fluent 14.0. User Defined Function hooked in the Software is given to couple the motion of cylinder to flow motion. For simulation of free surface, volume of fluid method is used. The effect of free surface is investigated with using a comparison of transverse displacement diagrams and aerodynamics coefficients diagrams for the two gap-ratios. With approaching cylinder to free surface, results show an abatement in the lock-in region and the amplitude of the oscillations and aerodynamics coefficients are changed depending on the Reynolds location branch.

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1- Introduction

Vortex-Induced Vibration (VIV) is a fundamental phenomenon frequently used 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 influences 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 to investigate the free vibrations of a circular cylinder of low mass ratio in the 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 et al. [4] used a numerical solution of the special integral form of two-dimensional continuity and unsteady Navier–Stokes equations to investigate the vortex's states of a horizontal cylinder undergoing forced oscillations in the free surface water wave. Their study aims to examine the consequence of degree of submergence of the cylinder beneath the free surface at Froude number of 0.4. Calculations are carried out for a single set of oscillation parameters at *Re*=200.

The entire review clearly indicates the two-degree-of-freedom VIV of an elastically supported circular cylinder beneath a free surface which has not been studied. 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 VIV in an unlimited fluid

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

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

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

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:

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

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

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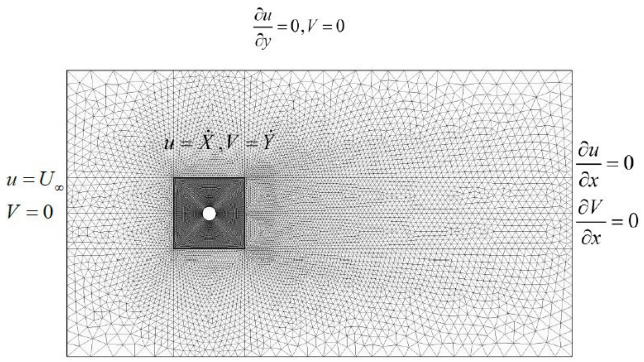

Fig. 1. Grid topology for Vortex induced vibration simulation and its boundary condition

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 in Ansys Fluent, using a finite volume solver. The response of the cylinder can be obtained by applying an explicit integral method on Eqs. (3) and (4), with the drag and lift coefficients appearing on the right-hand side of the equations as calculated by using the Fluent solver, so that the interactions between the fluid and the cylinder are properly accounted for. To do this, the User Defined Function (UDF), written in C programming language, is hooked to the main code of the Fluent solver. Before presenting the main results, we shall establish the validity of our numerical simulations. Fig. 2 demonstrates the good agreement obtained with the data presented in Fig. 2 of Ref. [5].

2- 2- Fluid flow simulation around a fixed cylinder near the Free Surface

Rrefering to Hosseinalipoor and Haji ghafoori boukani [6], 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. (In the paper, Fr = 0.2, 60 < Re < 150)

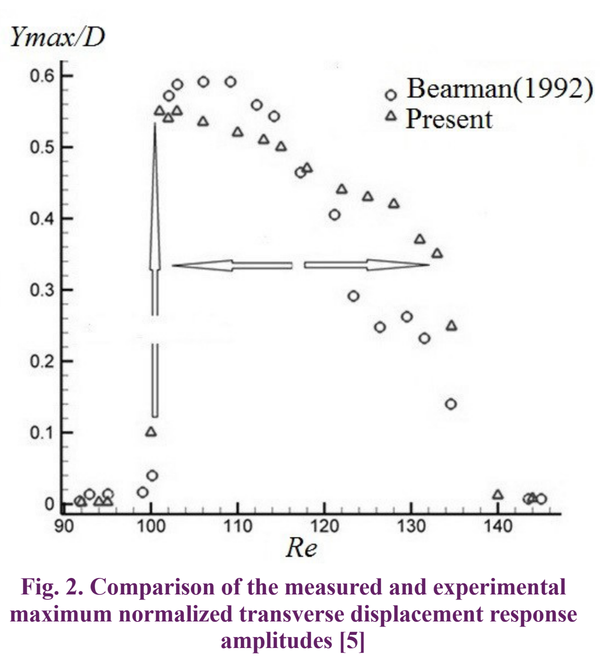

Fig. 2. Comparison of the measured and experimental maximum normalized transverse displacement response amplitudes [5]

3- Results and Discussion

Fig. 3 shows Cross response in terms of the Reynolds number. In the interpretation of VIV response, in general, it has three branches: primary, lower and upper, it can be seen that if there will be a free surface of fluid, the branches are inseparable (like without Free surface) and reduced. Changes of Lift coefficients is shown in the Fig. 4. Jump in high branches for both the beginning and end are visible in the diagram. In general with approaching the cylinder to the free surface, results shows an abatement in lock-in region and the amplitude of the oscillations and aerodynamics coefficients are changed depending on the Reynolds location branch.

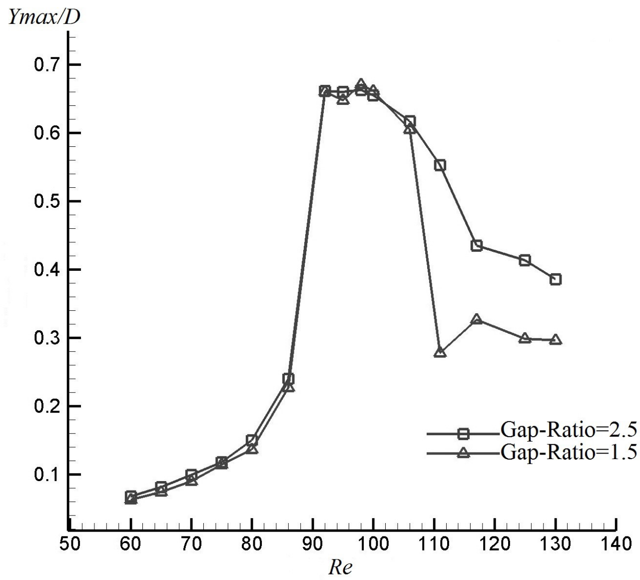

Fig. 3. Variations of the maximum normalized transverse displacement response amplitudes at *Gap – Ratio* = 2.50, 1.50

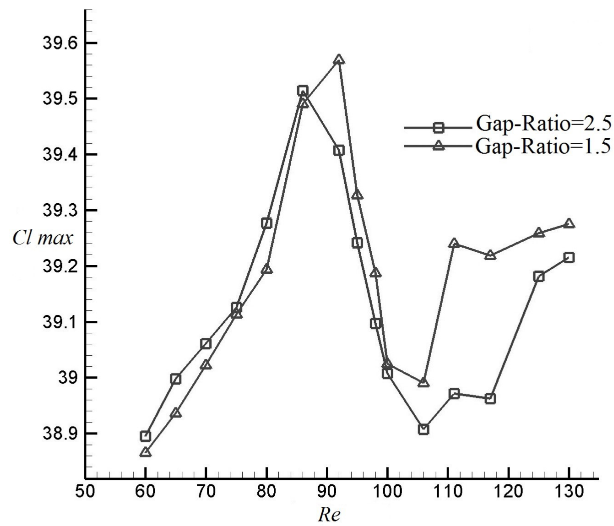

Fig. 4. Variations of the maximum Lift coefficient amplitudes

4- Conclusions

In this paper, the vibrations caused by vortex shedding flow around a cylindrical 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. Here is some results: transversal oscillations is much larger than the longitudinal oscillations, free surface does not lead to fundamental changes in VIV phenomenon, and free surface reduces longitudinal and transversal oscillations.

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