# NUMERICAL STUDY OF VORTEX INDUCED VIBRATION OF CIRCULAR CYLINDER

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**Abstract.** In many ocean engineering, vortex induced vibration of slender structures such as a riser has long been a nemesis to be investigated and yet to be fully understood. Numerous experimental and computational studies approaches have reveal the many aspects of the phenomenon and tried different measures for mitigation of the related damages. However, due to complexity of interaction between deformable structure and unsteady hydrodynamic forces, both experimental and computational models are not easy tasks. In this study, a computational fluid model is applied to simulate the unsteady flow passing the circular cross section while the body is freely moving under the influence of hydrodynamic forces caused by vortex shedding. Finite volume method is utilized. In order to implement the movement of the body influenced by the hydrodynamic force, meshes around the moving body are reconfigured considering the new location at every time step of computation. Both mechanical damping and stiffness are assumed when the equation of motion of the oscillatory body is solved at every time step. One degree of freedom with damping and stiffness in cross-flow direction is considered with free oscillation under the influence of hydrodynamic forces caused by vortex shedding. The results show that the maximum amplitude of the cross flow vibration exceeds more than half of the diameter of the cylinder and it can deform the whole system to a great extent. In particular, two distinct periods of fluctuating hydrodynamic forces are identified with smaller periods corresponds to secondary shedding between primary vortex shedding due to shear caused by movement of the body. In addition, vortex shedding of frequency near the natural frequency of the structural system clearly reveals the lock-in behavior and the large divergent movement is also observed with lower damping.

## 1 INTRODUCTION

Recent interest in utilization of sea water for new form of energy requires efficient intake system which often employs a long riser through the ocean current. KRSIO of Korea has been developing a deep seawater system and the marine riser has been used as an important component of intake system.

The riser for deep seawater intake should be stable for structure integrity and should be functional for its own purpose. In general, the marine riser has the characteristics of a flexible elongated body structure with a full-length is very long and the diameter/length aspect ratio is large (Fig. 1). This structure is under the action of ocean currents that originate forces and periodic movements that influence its behavior detrimentally, inducing vibrations in the structure known as vortex induced vibrations (VIV) and causing the risk of fatigue failure. Therefore, it is essential to evaluate fluid load and structural response.

The purpose of this study is to understand the dynamic behavior of the riser by computational analysis of free vibration of the two-dimensional circular cylinder in laminar flow.

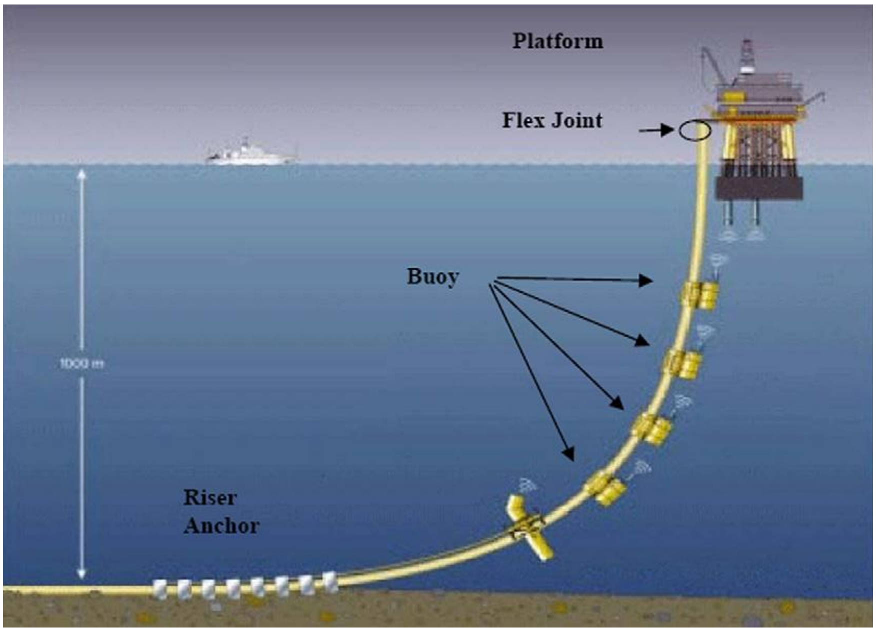


**Figure 1**: Deep seawater system *(Image Courtesy : Google Images)*

## 2 COMPUTATIONAL METHOD

### 2.1 Governing Equations and numerical method

In this paper, VIV on marine risers is investigated by numerical study of two-dimensional unsteady flow over circular cylinder for low Reynolds number. The flow field is governed by the Navier-Stokes equation and the continuity equation for Newtonian incompressible fluid, which read as

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

$$\rho\left(\frac{\partial u_i}{\partial t} + u_j\frac{\partial u_i}{\partial x_j}\right) = -\frac{\partial p}{\partial t} + \frac{\partial}{\partial x_j}\mu\left(\frac{\partial u_i}{\partial x_j} + u_j\frac{\partial u_j}{\partial x_i}\right) = 0 \tag{2}$$

where $u_i$ is velocity, $\rho$ is density, $p$ is pressure, $\mu$ is kinematic viscosity and $i, j$ indicate two dimensional spatial coordinates which have values 1, 2.

The pressure interpolation scheme adopted was PRESTO which is useful for predicting highly swirling flow characteristics. In order to reduce the effects of numerical diffusion, a second order upwind scheme was used for spatial discretization. And also the PISO algorithm was used for coupling the pressure and velocity.

## 2.2 Geometry and boundary conditions

Fig. 2 depicts the computational domain and meshes employed in the study. By denoting D as the diameter of the circular cylinder and assuming the free stream flowing from left to right, the domain consists of upwind region of length of 11D and downwind region of length of 45D while the size of the domain in cross wind direction is 25D. The total number of grids is 29000 and the smallest grid size is about D/64.

Since the cylinder is oscillating freely under the influences of both hydrodynamic forces and the structural forces from stiffness and damping, this study employs the strategy of dynamic mesh incorporating the moving boundary. Fig. 3 depicts the region where the smoothing is processed at every time step (Moving Zone) and the remaining part is fixed in time (Stationary Zone).

The physical boundary conditions for inlet on the left and outlet on the right are uniform inflow and zero velocity gradient, respectively. Slip condition is set on the both sides and noslip condition is imposed on the surface of the cylinder.

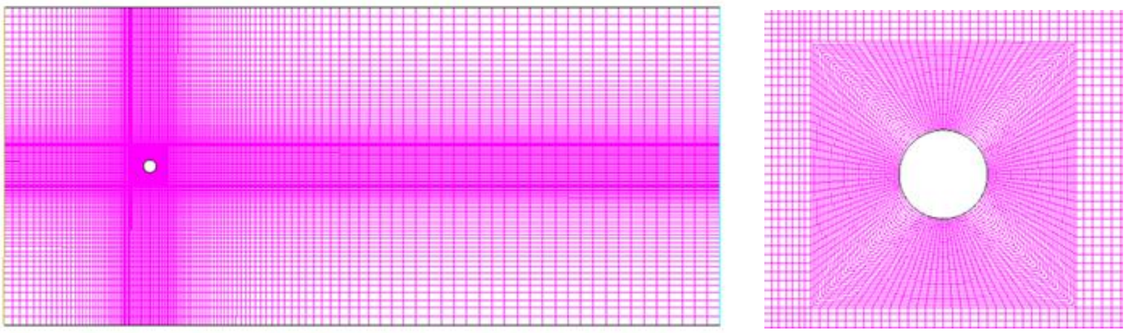

**Figure 2**: Computational domain and mesh distribution

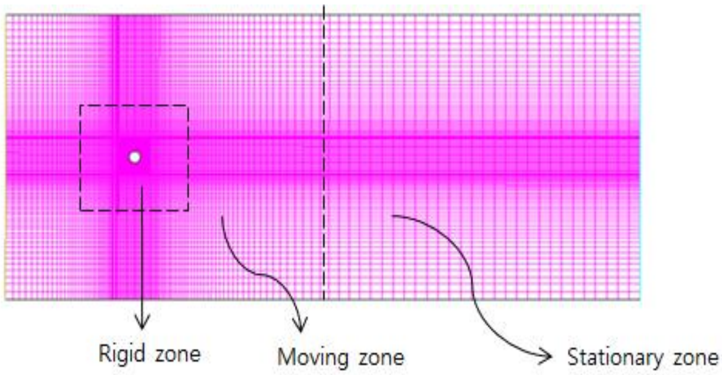


**Figure 3**: Moving and stationary zones

## 2.3 Dynamic mesh update method

For dynamic mesh, this study employs spring-based smoothing method in which the edges between any two mesh nodes are idealized as a network of interconnected springs. The initial spacing of the edges before any boundary motion constitutes the equilibrium state of the mesh. A displacement at a given boundary node will generate a force proportional to the displacement along all the springs connected to the node. Using Hook's Law, the force on a mesh node can be written as

$$\vec{F_i} = \sum_{j}^{n_i} k_{ij} \left( \Delta\vec{x_j} - \Delta\vec{x_i} \right) \tag{3}$$

where $\Delta\vec{x_j}$ and $\Delta\vec{x_i}$ are the displacements of node *i* and its neighbor *j*, $n_i$ is the number of neighboring nodes connected to node *i*, and $k_{ij}$ is the spring constant (or stiffness) between node *i* and its neighbor *j*. The spring constant for the edge connecting nodes *i* and *j* is defined as

$$k_{ij} = \frac{k_{fac}}{\sqrt{|\vec{x_i} - \vec{x_j}|}} \tag{4}$$

where $k_{fac}$ is an empirical value.

At equilibrium, the net force on a node due to all the springs connected to the node must be zero. This condition results in an iterative equation such that

$$\Delta\vec{x}_i^{m+1} = \frac{\sum_j^{n_i} k_{ij} \Delta\vec{x}_i^m}{\sum_j^{n_i} k_{ij}} \tag{5}$$

where *m* is the iteration number. Since displacements are known at the boundaries (after boundary node positions have been updated), Eq. (5) is solved using a Jacobi sweep on all interior nodes. At convergence, the positions are updated such that

$$\vec{x}_i^{n+1} = \vec{x}_i^n + \Delta\vec{x}_i^{converged} \tag{5}$$

where *n+1* and *n* are used to denote the positions at the next time step and the current time step, respectively.

## 2.4 Cylinder motion

The cylinder moves accordingly with balances of inertial forces and hydrodynamic force which is lift normal to the inflow in this case of 1 DOF (degree of freedom) in the cross wind.

The nondimensional equation of motion of the cylinder is as follows;

$$m\ddot{x} + c\dot{x} + kx = F(t) \tag{6}$$

where $m, c, k, F(t)$ are mass per length, damping coefficient, spring constant and unsteady lift, respectively. By defining $C = 2\xi\left(\frac{2\pi}{U_{red}}\right)$ and $K = \left(\frac{2\pi}{U_{red}}\right)^2$ where $U_{red}$ represents reduced velocity , $U_{red} = \frac{v}{f_n D}$ and ξ is normalized damping coefficient $\xi = \frac{c}{2\sqrt{km}}$, eq. (6) yields to

$$\ddot{x} + C\dot{x} + Kx = \frac{1}{2n}C_F \tag{7}$$

The schematic view of the problem is shown in Fig. 4 and the Eq. (7) is numerically solved by second order Runge-Kutta method to determine the position of the cylinder.

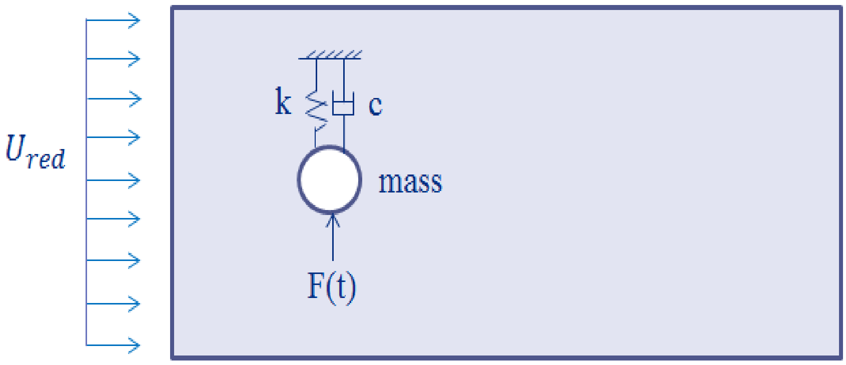


**Figure 4**: Computational method of fee vibration

## 3 RESULTS

Computations are carried out for *Re*=90 to 140 where $Re = \frac{\rho UD}{\mu}$. Fig. 5 shows the comparison of $f/f_N$ from present study and previous ones [5-8] where $f, f_N$ are vortex shedding frequency and structural natural frequency. The present results are in good agreement of others including lock-in phenomenon.

## 4 CONCLUSIONS

This study presents a computational study for freely oscillating circular cylinder under the influence of vortex shedding in order to understand VIV of a marine riser which is an essential component of deep seawater intake system which is under development by KRISO, Korea.

A finite volume model is applied to simulate the unsteady flow passing the circular cross section and 1 DOF (degree of freedom) of the body is allowed with designated stiffness and damping. The dynamic behavior of the body is incorporated into the fluid-structure interaction by using dynamic mesh.

The results show that the spring-based smoothing method for dynamic mesh reflects well the movement of the unsteady motion of the body. The results also show that the present method produces the vortex shedding frequencies in good agreement with previous studies and the lock-in phenomenon is well reproduced.

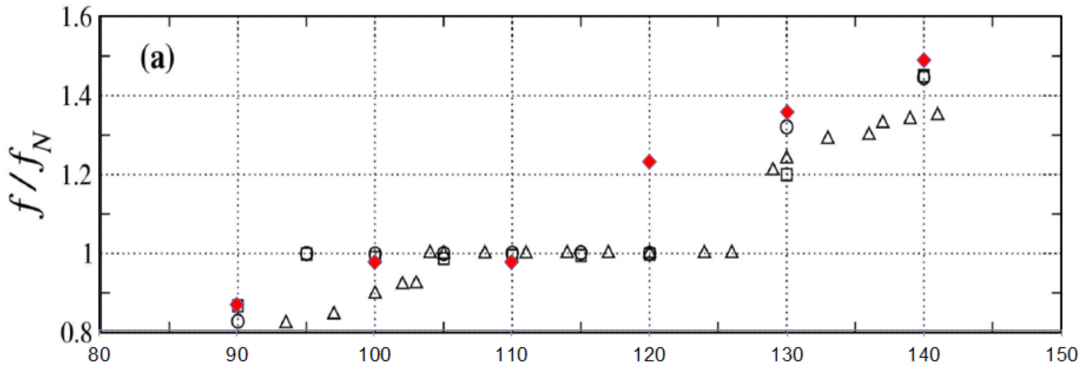


**Figure 5:** Comparison of the ferequency ratio of vortex shedding frequency and natural frequency; ◆ present study ○ computation in [1] □ computation in [2] ◇ computation in [3] △ Experiment [4]

## ACKNOWLEDGMENT

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