ISSN (online): 2349-784X

Modelling of Flow-Induced Pulsations in Subsea Applications

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Abstract

One of the classical problems in fluid mechanics is the determination of the flow field around a bluff body represented by a circular cylinder. This is of great interest in many engineering applications, such as hydrodynamic loading on ocean marine piles and offshore platform risers and casing pipes etc. The hydrodynamic behavior of the complex flow field around variety of circular cylinders shall be investigated. Wave induced vibration of structure such as marine pipelines, oil terminals, tanks and ships by placing oscillatory pressure on the surface of the structure. Flow-induced vibrations of slender marine structures can result from external or internal flows. VIV phenomenon is widely seen in subsea applications for risers, conductors, seabed pipelines and other subsea structures. FLIP occurs for rough bore flexible pipes, i.e. pipes with a corrugated metallic inner liner carcass is used for dry gas transport. As dry gas passes through a flexible riser, an unstable shear layer is generated off each of the internal corrugations which make up the internal carcass. Above a certain flow velocity vortices are shed from the carcass, at a frequency resulting in the generation and propagation of acoustic vibrations that lead to fatigue damage to topside and subsea small bore piping. The experimental work is carried to determine the dependence of the exact geometry i.e. corrugation geometry, length of the corrugated tube and the boundary conditions on the generation of pulsations. The obtained analytical tools will be validated by detailed CFD simulations and laboratory experimental tests.
Keywords: Vortex induced vibration, Flow induced pulsation, Flexible risers, Marine structures

I. INTRODUCTION

Many structures of practical importance such as pipelines, risers, and cables are not streamlined cause a fluid flow over the structure to separate from the contours of the structure. Such structures are called bluff bodies. For a bluff body in uniform cross flow, the wake behind the body is not regular but contains distinct vortices of the pattern at a Reynolds number greater than about 50. The vortices are shed alternately from each side of the body in a regular manner and give rise to an alternating force on the body. The phenomenon is so called Vortex Induced Vibration (VIV).

Cylinder vibration at or near the vortex shedding frequency organizes the wake and changes the fluid force on the cylinder. Vibration of a cylinder in a fluid flow can,

1) Increase the strength of the shed vortices
2) Increase the spanwise correlation of the vortex shedding
3) Cause the vortex shedding frequency shift from the natural shedding frequency to the frequency of cylinder oscillation.
4) Increase the drag on the cylinder
5) Alter the phase sequence and pattern of vortices

Waves induced vibration of structure such as marine pipelines, oil terminals, tanks and ships by placing oscillatory pressure on the surface of the structure. These forces are often well-represented by the inviscid flow solution for many large structures such as ships and oil storage tanks. For smaller structures, viscous effects influence the fluid force and the fluid forces are determined experimentally. The Morison equation is used to compute the wave forces on slender cylindrical ocean structures such as pipelines and piers.

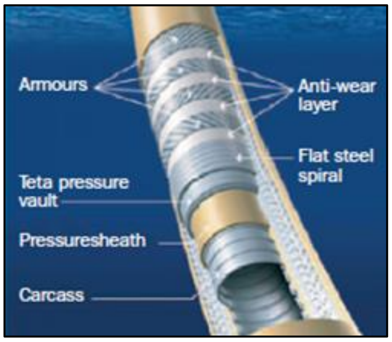


Fig. 1: Flexible riser with carcass profile [1]

The flow of a fluid through a pipe can impose pressures on the walls of the pipe causing it to deflect under certain flow conditions. This deflection of the pipe may lead to structural instability of the pipe. Flow Induced Pulsation (FLIP) occurs for rough bore flexible pipes, pipes with a corrugated metallic inner liner (carcass), used for dry gas transport. As dry gas passes through a flexible riser, an unstable shear layer is generated off each of the internal corrugations which make up the internal carcass. Internal flow through a pipe decreases the natural frequency of the pipe. Sufficiently high internal velocity will induce buckling in a pipe since the momentum of fluid turning through a pipe deflection is greater than the stiffness of the pipe.

The pressure pulsations are generated due to vortex shedding on corrugations of the innermost layer of the flexible riser carcass. These pressure pulsations can be sufficiently extreme to cause vibration induced piping fatigue failures. Dynamic pressures are also seen in the topside piping system. The full mechanism of FLIP is studied as,

1) The Strouhal number and characteristics
2) The gas velocity
3) The maximum pulsation amplitude and frequency

II. STANDARDS

1) MARNET – CFD Best Practice Guidelines for Marine Applications.

III. RESEARCH OBJECTIVES

The objective of this Research Project is to understand the Flow Induced Vibration phenomena and develop models predict the velocity for a range of pipe sizes and carcass profiles of flexible risers. Above a certain flow velocity vortices are shed from the carcass, at a frequency resulting in the generation and propagation of acoustic vibrations that lead to fatigue damage to topside and subsea small bore piping. The obtained analytical tools will be validated by detailed CFD simulations and experimental setup.

IV. RESEARCH METHODOLOGY AND PROBLEM APPROACH

The flow past offshore platform flexible risers and casing pipes of different diameters in three dimensional domain will be modeled and simulated using commercial CFD Software. The computational robust grid is generated with grid independent test. The Finite Volume Method (FVM) approach is used for numerical modeling and simulation of VIV and FLIP problem with active Turbulence models. The problem is extended to vibrational theory for pressure flow pulsations in flexible risers and acoustic vibrations lead to fatigue damage of topside piping. The analytical results are validated with computational work and laboratory experiments and thorough investigation is made in contrast to Subsea Oil & Gas.

A corrugated pipe is provided having a pipe structure of an inner wall having an interior surface and an exterior surface, and an outer wall having corrugations. In order for a system to be subject to flow induced pulsations, the following assumptions are considered.

1) It uses a flexible riser with a corrugated internal carcass
2) The riser as single phase gas flow

The problem attributed to flow induced pulsations (FLIP) are generated on the inner corrugated layer of the flexible riser. When the vortex shedding frequency is able to excite acoustic natural frequencies of topside piping or subsea manifolds, a resonance phenomenon occurs. This can cause excessive pulsation, vibration and noise levels in the topside and subsea piping.

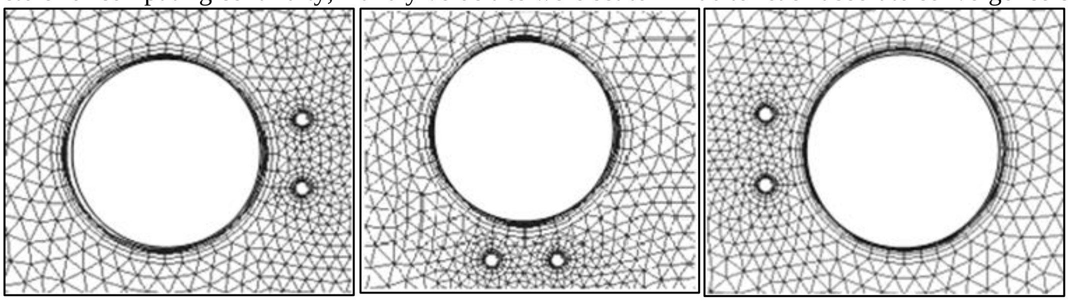
In the experiments the goal is to determine the dependence of the exact geometry i.e. corrugation geometry, length of the corrugated tube and the boundary conditions on the generation of pulsations. In the experiments the following as minimum are modeled and setup.

1) frequency response
2) acoustic damping
3) pressure drop
4) pressure dependence on pulsation frequency and amplitude
5) flow velocity at which on-set occurs

V. PREVIOUS RESEARCH

The previous Master Thesis by Research was studied as “Computational modeling and investigation of hydrodynamic forces around offshore risers and conductor pipes”.

The hydrodynamic behavior of the complex flow field around the three circular cylinders in tandem was investigated. Flow past three circular cylinders of different diameters in two dimensional domain was simulated using commercial software Ansys Fluent. Three different angles of attack with 0, 90 and 180 degrees were used in three pattern arrangement of the large circular cylinder respectively. The diameter ratio of the large cylinder to the small one is 14 with constant center-to-center distance. The segregated implicit solver approach was chosen with the SIMPLE (Semi-Implicit Method for Pressure Linked Equation) method by Patankar (1981) to achieve pressure-velocity coupling and the field variables are interpolated using the first order upwind scheme. The second order pressure discretization was chosen for good resolution during capturing of pressure field near cylinder. The residual factors for computing continuity, x and y velocities were set to 1E-06 to reach absolute convergence criteria.



Right aligned, α =180 Bottom aligned, α = 90 Left aligned, α = 0

Fig. 2: Alignment of offshore foundation in a fixed horizontal flow direction.

Validation experiments were conducted in four stages: Grid independency, center-line velocity profile, vortex shedding lift profile and drag force prediction against Reynolds number. Validation for higher turbulent region fails when a standard KE turbulence model was used to predict the drag coefficients around cylinder resulting 25% error. The simulations were carried though pointing this limitation governs and few techniques for minimizing this error was identified and discussed as a hypothesis.

A total of 65 simulation runs were carried which include steady and unsteady state solutions. Various contour and x-y plots of static pressure, velocity magnitude, drag coefficients, convergence etc. were computed for computational analysis. A couple of animations were also made in MPEG format at Re 150 for identifying vortex behavior and demonstration purpose.

A. Achievements

The major achievements of previous thesis are summarized below:

1) To study and understand the concept of hydrodynamic behavior of offshore foundations and defining the specific problem
2) To check the compatibility, simulate and examine the computational hydrodynamic model
3) To calculate the hydrodynamic drag forces for a steady current flow and validate the numerical results with experimental data and up scaling to real conditions
4) To investigate the interaction of flow behavior around offshore foundations
5) To perform feasibility studies for numerical simulation of fluid-fluid (air-water) interaction

B. Computational Validation

The formation of two wakes at Re 20 in a steady current flow can be seen in Figure 3. For Re>40, the boundary layer over the cylinder surface will separate due to adverse pressure gradient imposed by the divergent geometry of the flow environment at the rear side of the cylinder. As a result, a shear layer is formed downstream of the separation point and causes the layer to roll up into a vortex.

The validation parameters for this study are:

1) Center-line velocity profile
2) Strouhal number (St) and
3) Reynolds number (Re)

C. Analysis of Results

The present numerical simulation at lower and higher Reynolds number has revealed many of the features characterizing the flow around three un-identical cylinders in tandem arrangements. Flow past an offshore monopile foundation with three different angles of attack 0, 90 and 180 degrees was studied using a commercial package Ansys Fluent. The diameter ratio of the large cylinder to the small one is 14 with constant center-to-center spacing. The two dimensional Navier-Stokes equations were solved by using Finite volume method.

Code validation was undertaken on three different geometries. Geometry3 which consist of 19494 cells with a Tripaved mesh shows good agreement to proceed for computing coefficient of drag. A standard KE turbulence model with enhanced wall treatment and standard industrial constants was used. But still when higher turbulence was applied, Reynolds number validation fails showing 25% error during computation of drag forces in molecular viscous region around cylinder. A fully engineered grid with periodic boundary condition specifying law of the wall and further increase in the mesh density from 19494 to 35000 cells may raise to reduce this error. However to achieve this, the computational time increases potentially for transient simulations with increase in number of cells. Further Strouhal number validation for vortex shedding gives very good agreement with an error +/-0.63%, which is acceptable. A centre-line velocity profile shows very good agreement which confirm flow computations are running correctly.

The hydrodynamic flow filed of upscale models for higher velocities 5 m/s and 10 m/s for all three different angles of attack were studied. Keeping the limitation of drag force validation inactive, the results showing several plots gives good agreement for predicting the flow behavior for three cylinder problem. This was achieved in analogous with the flow over a single cylinder and finding for anomalies. The wake formed was shielded originating from the vicinity of the cylinder. For an angle of attack of 90 degrees, the drag forces computed were higher on one of the two small cylinders. The affect of drag forces for large cylinder due to small cylinders shows no variations and of no significant importance. But surprisingly the results reported a change in hydrodynamic field around wake region showing shift of wake towards small cylinder and a wake of conical shape. The numerical work has been limited for further investigation of this kind of behavior.

VI. CONCLUSION

The concept of Vortex induced vibration (VIV) and Flow induced vibration (FLIV) is envisaged to study for carcass profile of flexible risers, conductors, seabed pipelines and other subsea structures. FLIP occurs for rough bore flexible pipes, i.e. pipes with a corrugated metallic inner liner carcass is used for dry gas transport. The full mechanism of FLIP is studied as,

1) The Strouhal number and characteristics
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APPENDIX

A. Few Plots from Previous Research

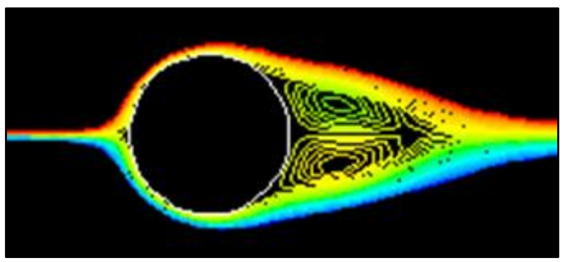

Fig. 3: Contour of Stream function at Re<20

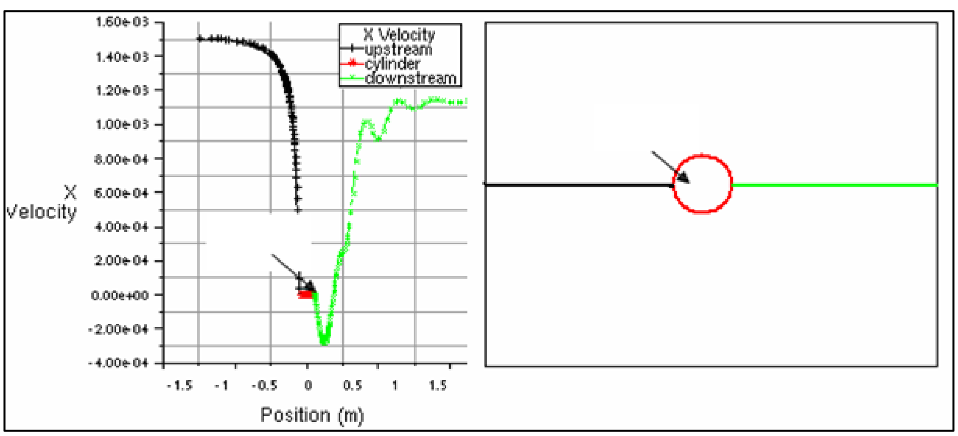

Fig. 4: Center-line Velocity profile in x-direction for a computational domain.

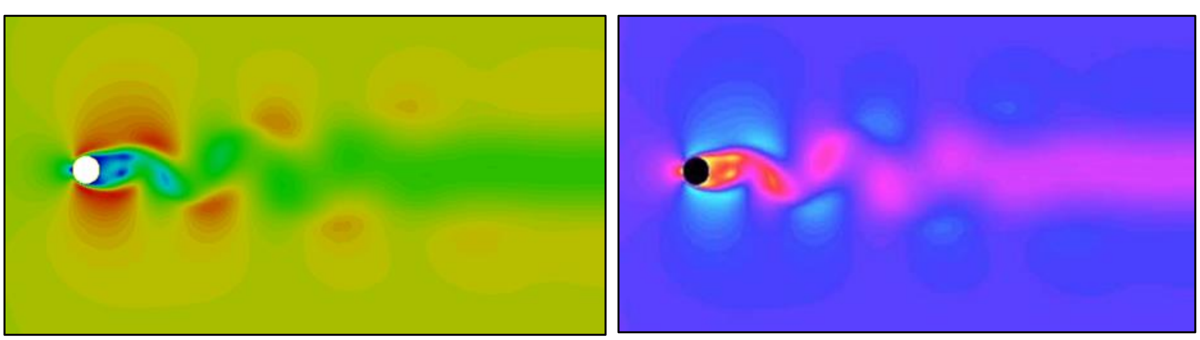

Fig. 5: Plot of velocity magnitude at Re = 150, Flow time = 4000 seconds, laminar, Positive photo (left), Negative photo (right), ANSYS Fluent Inc.

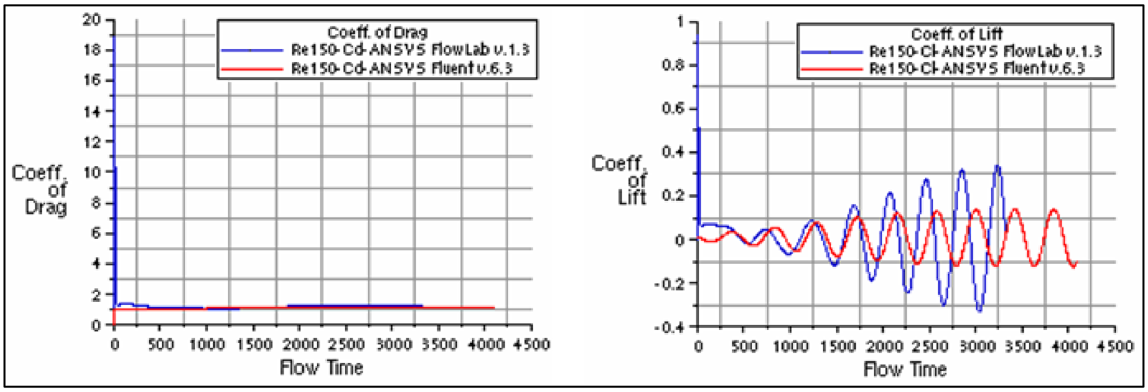

Fig. 6: Validation plots showing coefficient of drag and lift for unsteady state.

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