Numerical Modelling of Hydrodynamic Coefficients for Piggyback Pipeline

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Abstract

Hydrodynamic loadings play a very important role in the stability of submarine pipelines. The cost of installing the pipelines can be up to 40%-60% of the total cost of offshore facilities. One of the main techniques proposed is pipeline bundles where two or more pipelines are strapped together. A popular way of combining the bundle is to strap a smaller diameter pipeline onto the main pipeline. This gives rise to a piggyback configuration. This paper will investigate the influence of the piggyback on the hydrodynamic loadings on the system in steady current and also wave plus current situation using a Computational Fluid Dynamics (CFD), FLUENT.

1.0 Introduction

Offshore pipelines are usually subject to wave and current loading. This will exert forces on the pipelines which later may result in pipeline failure if the design limits are exceeded. It is expected that the existence of the piggyback pipeline will have some effects on the hydrodynamic forces of the main pipeline. The flow behaviour around these pipelines is more complicated than a single submarine pipeline. This will require a different way of designing the pipelines configuration to ensure that the piggyback pipeline is stable and not susceptible to fatigue damage due to vortex induced vibrations (VIV). This can be achieved by increasing the mass of the pipelines via a concrete weight coating or increased wall thickness. However, this can result in significant cost and may adversely affect pipeline handling and installation. In the North West Shelf, pipelines are used to transport condensate, oil, LPG and also natural gas. As the density of natural gas is less than the surrounding water, the pipeline tends to float and vibrate under certain conditions which will cause fatigue damage in the long run. Thus, there is a need for detail examination to study the ways in which the external hydrodynamic loadings can affect this type of configuration.

Even though much theoretical and experimental research has been done to study the hydrodynamic characteristics on twin and multiple cylinder configurations, most appears to be confined to cylinders of equal diameter. Very little information is available on the effect of hydrodynamic forces on the main pipeline with a piggyback configuration. Due to this lack of knowledge, the optimum design to minimise the forces are not well-known. The design practice of the piggyback configuration is still at a conventional stage where equivalent diameter approach is used and its validity has not been extensively researched. Equivalent diameter approach assumes that the diameter is equivalent to the sum of the main and piggyback pipeline together with the gap between the pipelines.

Therefore, the purpose of this paper is to find the optimum hydrodynamic coefficients for the piggyback pipeline in steady current and wave plus current loadings. This paper will also investigate the various piggyback orientations with different flow conditions to account for the changes in the ocean environments.

1.1 Project Aim and Scope

The aim of this research is to analyse the hydrodynamic characteristics of an offshore pipeline in piggyback configuration exposed to steady current and combination of wave-current loading, by using a Computational Fluid Dynamics (CFD) package, FLUENT.

2.0 Background Theory

Pipeline exposed to steady current will experience an in-line force as well as transverse force. The magnitude of these forces depend on the Reynolds number. This phenomenon is due to the boundary layer in the viscous region around the pipe surface. The in-line force is called as drag force and the transverse force is always referred to as lift force. The contribution of drag and lift forces are the results of the skin friction and also the pressure distribution around the pipe that acts in-line and normal to the flow respectively. They can be represented as;

$$\overline{F}_D = \frac{1}{2}\rho C_D A U|U| \quad \text{and} \quad \overline{F}_L = \frac{1}{2}\rho C_L A U|U|$$

Where Cd and Cl is the drag and lift coefficient respectively.

In wave plus current flow, the flow is governed by an additional parameter called the Keulegen-Carpenter (KC) number. In the in-line force component, there exist an added mass effect due to the acceleration of the flow that results in inertia force. The in-line component of an oscillatory flow can be described as;

$$F_D = \frac{1}{2}\rho C_D A U|U| + \rho C_M A U\& \quad \text{where } C_M \text{ is the inertia coeffcient.}$$

This is known as the Morison equation which is used to analyse hydrodynamic loading on offshore structures and pipelines.

2.1 Wave Current Interaction

It is a common occurrence in ocean environments that wave and current will coexist. In fact, many offshore structures are located in areas where waves propagate on currents generated by tidal forces, density differences or wind. The presence of current usually is in turbulent form but is approximated by corresponding mean flow (Chakrabarti, 1990). It has been found that due to the interaction of wave and current, the characteristics of the two are no longer the same in the case of wave and current alone. The overall diffraction effect and resultant loading can be significantly different from wave and current only effect (Celebi, 2000). The effect on offshore structures in wave-current field is different due to the changes in the parameters on wave and current such as the velocity, wave length etc. Chakrabarti has reported that the presence of current will alter the shape and size of the wave. Therefore the boundary layer interaction is not a linear superposition between wave and current but a lot more complex than that. However, since a method is not well-established yet in this area, a linear superposition will be used to simulate wave plus current.

3.0 Methodology

A 2D numerical domain was created to represent the model and its vicinity. Consideration was given to the grid around the wall of the cylinder to capture the interactions between the vortices that highly contribute to the hydrodynamic forces. Research was carried to simulate wave and current for the model. A User Defined Function was developed to model wave and current with specified depth and time varying velocity profile. The boundary layer for current was defined according to the specification in DNV RP E305 described in Equation 3.1 while a linear wave theory was used to define the near bottom wave boundary layer (Equation 3.2). Five orientations of piggyback configurations are simulated with β=0, π/4, π/2, 3 π/4 and π as defined in Figure 1.

$$U_c(z) = \frac{U^*}{\kappa}\ln\left(\frac{z+z_0}{z_0}\right)$$ **Equation 3.1**

$$U_w(z) = \frac{\pi H}{T}\frac{\cosh[k(z+d)]}{\sinh(kd)}\cos(kx-\sigma .t)$$ Equation 3.2

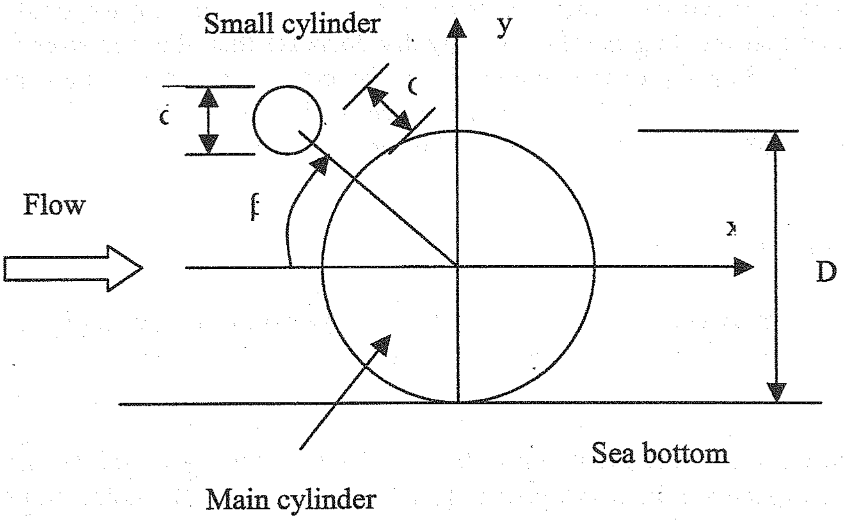
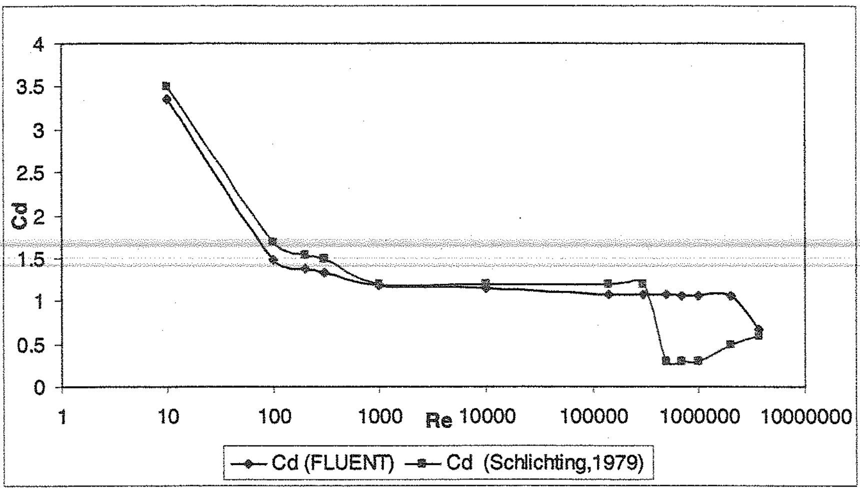


Figure 1

3.1 Validation of Model

Validation of the numerical model is essential for the dependability of the numerical results. This is done through calibrating the numerical results against published data. In this research, the numerical model was validated for both steady current and pure oscillatory flow case. In the steady current validation, both free stream cylinder and a wall mounted cylinder were validated. It has been found that the numerical model corresponds well with the published data with less than 10% of difference. However, it was found that FLUENT fails to capture the drag crisis region ($3.5x10^5 < Re < 1.5x10^6$). This region of transition from laminar to turbulent boundary layer separation is often not captured by conventional commercial CFD package. Figure 2 shows the comparison of results between FLUENT and Schlichting, (1979).



Comparison of drag coefficients for a free stream cylinder

Figure 2

For a boundary layer flow, a cylinder resting on the seabed was simulated for Reynolds number of $1x10^4$ and it was found that the drag coefficients slightly decrease than the free stream cases. The Reynolds number is defined on top of the cylinder in the boundary layer flow. The results of these coefficients can be found in Chapter 4. This is in agreement with experimental results by Jensen, et. al (1990) and Kiya, M.(1968) (as cited in Sumer and Fredsoe, 1997).

4.0 Analysis and Discussion of Results

The results of the lift and drag coefficients for the different orientations of the single piggyback are presented graphically below with different Reynolds numbers. The equivalent cylinder was also simulated to quantify the Equivalent Diameter Approach.

From the graphs shown, it can be seen that, when the piggyback is right on top of the main cylinder, the main cylinder will experience the maximum drag. This is true for all Reynolds numbers. As for the lift force, the main cylinder will experience the minimum lift force with the same configuration. This may be due to the pressure distribution around the pipe that influences the forces. The same phenomenon is observed when the cylinders are normalised against the equivalent diameter. It is also observed that with configuration of $\pi/2$, the drag coefficient computed underestimated the Equivalent Diameter approach by about 50%. The bundle will experience higher drag force with the piggyback. The theory of Equivalent Diameter predicts quite well with other piggyback configurations other than $\pi/2$.

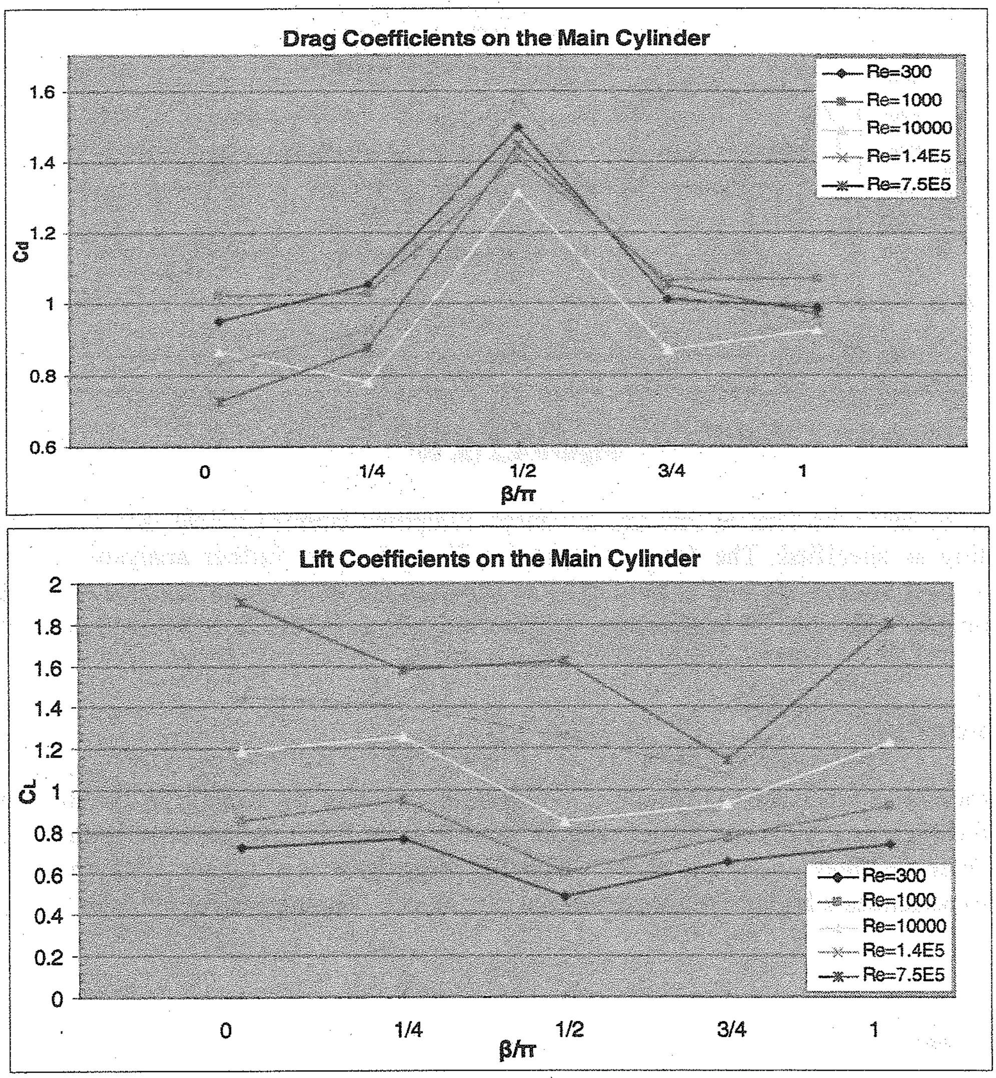
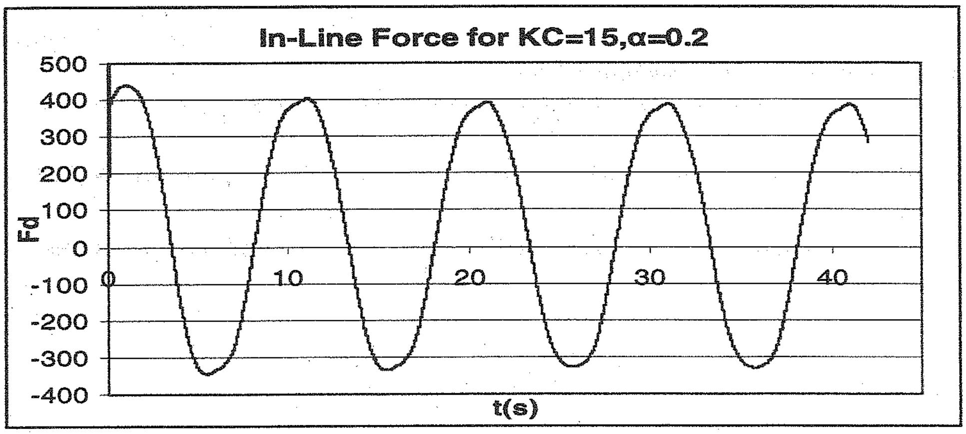

Drag Coefficients on the Main Cylinder
Cd
1.6
1.4
1.2
1
0.8
0.6
0
1/4
1/2
3/4
1
β/π
Re=300
Re=1000
Re=10000
Re=1.4E5
Re=7.5E5
Lift Coefficients on the Main Cylinder
CL
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
1/4
1/2
3/4
1
β/π
Re=300
Re=1000
Re=10000
Re=1.4E5
Re=7.5E5

Figure 4.1 (a, b)


In-Line Force for KC=15,α=0.2
Fd
500
400
300
200
100
0
-100
-200
-300
-400
0
10
20
30
40
t(s)

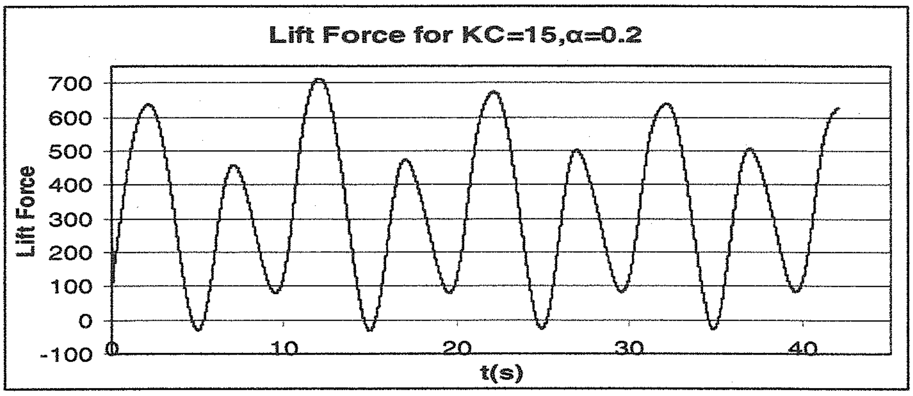


Figure 4.2 (a, b)

Figure 4.2 (a, b) show the total in-line and lift force computed from FLUENT due to the wave and current loading as specified. The forces obtained will need to be further analysed to obtain the coefficients. Least Square Method is employed to separate the total in-line force into the drag and inertia coefficients while the lift coefficients will be analysed using the Root Mean Square of the lift forces.

5.0 Conclusion

It has been found that when the piggyback is sitting right on top of the main pipe, the main pipe will experience the highest drag force. However, the lift force for this configuration is minimum. The Equivalent Diameter theory does not fit well when the piggyback is at the top of the main cylinder. The bundle experiences a higher drag than the one predicted by the equivalent cylinder.

6.0 References

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