CALCULATION OF HYDRODYNAMIC FORCE COEFFICIENTS FOR OSCILLATING FLEXIBLE RISERS USING NUMERICAL SIMULATION

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1. Introduction

Deep-sea oil industry is currently demanding a riser technology capable of provide profitable oil extraction at water depths of more than 3000m. Nevertheless, the numerical prediction of the dynamic response of an oscillating riser is still challenging due to the fact that interaction between the riser and the fluid surrounding it generates a complex mechanism in which the magnitude and the nature of the hydrodynamic forces acting on the riser are strongly related to the dynamic response of the riser. Therefore, an accurate prediction model for risers can only be realized if these force coefficients correspond to a specific modeling condition achieved by the riser at a given time. In this paper a numerical procedure for calculation of hydrodynamic force coefficients for oscillating risers is presented. The proposed procedure is validated using experimental data and simulation results obtained from previous research work at low values of beta parameter.

2. Modeling Considerations

Existing semi-empirical models for response prediction of risers highly depend on the experimentally derived values of hydrodynamic force coefficients. On the other hand, the quasi-steady approach states that hydrodynamic force coefficients can be used for oscillating flexible risers by assuming that static fluid forces due to oscillatory flow can be used to predict hydrodynamic forces acting on an oscillating body. A more straightforward approach is the modeling of the sinusoidal movement of the cylinder in the in-line direction while computing the cross-flow forces due to shed of vortices. In this paper a numerical model for prediction of in-line hydrodynamic force coefficients is developed using the commercial finite volume CFD code, named FLUENT [1]. Fig. 1 depicts the computational domain. D is the diameter of the cylinder. Then, a blockage ratio (D/B) of 10% is selected in this paper based on the simulation results presented by Anagnostopoulos and Minear [2], who performed a parametric study using blockage ratios ranging from 10% to 50% and found that the blockage effect is almost negligible for blockage ratios lower than 20%. The final grid is composed of 17494 nodes. The cylinder is placed in the center of a circular domain composed of triangular cells. The remaining regions of the computational domain are composed of quadrilateral cells. The solution is time-dependent (time step value of 0.01 seconds). Therefore, an unsteady solver is used herein allowing the modeling of the oscillatory flow condition.

3. Model Validation

A fixed value of beta parameter (β=Re/KC) of 120 and Keulegan-Carpenter (KC) numbers ranging from 0.98 to 4.9 are selected for the validation of the proposed model. Based on the Reynolds (Re) numbers achieved by the model, a laminar viscous model is selected. The proposed model is first validated for steady flow at Re=100. Zhou and Graham [3], using a vortex-based method to simulate flow around a circular cylinder, found a mean drag coefficient value of 1.37. The model proposed in this paper is therefore implemented for the same simulation conditions presented by Zhou and Graham [3]. The C_{Dmean} value computed from the proposed model is remarkably similar to the one presented by Zhou and Graham [3] having a value of 1.38. Oscillatory flow with KC numbers ranging from 0.98 to 4.9 and period of 2 seconds is simulated using a user defined function (UDF) developed by the authors. C_{Dmean} and C_m are then calculated through least squares fit of the force time series. Obasaju et al. [4] experimentally found that there is a range of β in which C_{Dmean} is not sensitive to changing β. It was identified that the upper boundary of the range lies between β=964 and 1204. Therefore, the simulation results obtained from the proposed model are compared with the ones found by Anagnostopoulos and Minear [2] at β=50, Obasaju et al. [4] at β=196, Lin et al. [5] at β=70 and Bearman et al. [6] at β=200 as shown in figs. 2 and 3.

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Finally, the proposed model is numerically implemented for the oscillating body case. The moving/deforming mesh capability provided by FLUENT [1] is used herein to sinusoidally move the cylinder in the in-line direction while applying pressure forces in the cross-flow direction based on the explicit Euler formulation presented in Eq. 1.

$$v_t = v_{t-\Delta t} + (F / m_0)\Delta t \tag{1}$$

where v_t is the velocity of the cylinder in the cross-flow direction and F is the pressure force in the same direction at a given value of time t. $\triangle t$=0.001 seconds. The aforementioned procedure is repeated at each time step. The simulation results for the oscillating body case are also presented in figs. 2 and 3.

4. Results and Discussion

It can be seen from fig. 2 that the values of the C_{Dmean} computed from the oscillatory flow and oscillating body cases are in good agreement with the experimental and simulation data provided by previous studies. It is also important to highlight that for the oscillating body case C_i is obtained through least squares fit of the force time series and it is assumed that C_m=C_i+1.0. The computed values of C_m show lower values than the ones obtained from the oscillatory flow case showing the importance of fluid-structure interaction, which is expected to be significant at large amplitudes.

5. Conclusions and Future Directions

A numerical model for calculation of hydrodynamic force coefficients for oscillating flexible risers was presented. The proposed model was experimentally and numerically validated using data from previous research work. Good agreement was found in these comparisons. Further research work is needed in order to develop an elastically mounted cylinder model for the prediction of the cross-flow response in oscillating flexible risers.

References

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Figures

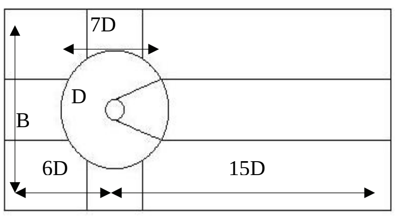

Fig. 1 Experimental and Analytical Results

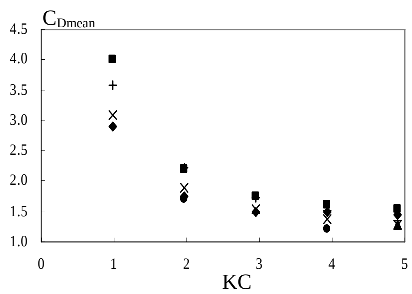

Fig. 2 C_{Dmean}:■Anagnostopoulos and Minear[2] ◆Lin et al.[5]; ▲Obasaju et al.[4]; •Bearman et al.[6]; Present Results (×Oscillatory Flow; +Oscillating Body).

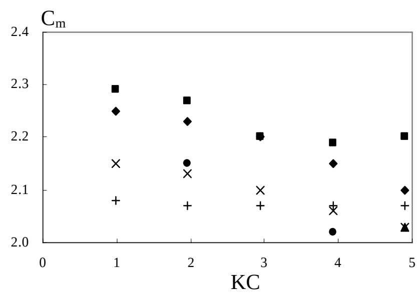

Fig. 3 C_m:■Anagnostopoulos and Minear[2] ◆Lin et al.[5]; ▲Obasaju et al.[4]; •Bearman et al.[6]; Present Results (×Oscillatory Flow; +Oscillating Body).