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EXTENDED ABSTRACT

Investigating into the Temporal Hydrodynamic Forces Exerted on Offshore Piggyback Pipelines due to Steady Currents

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1. Introduction

For the gas and oil pipelines in marine environment, the forces exerted on these structres are regarded to be of the important parameters in designing them. These pipelines are usually installed with twin arrangements as tandom or side by side. The diameters of the two pipelines may also be identical or different. Neverthless, a number of them may also be configured as piggyback, an special case of side by side arrangements when their diameters are not equal. The parameters around this special arrangement have already been studied both experimentally and numerically by a few number of researchers, namely, Zhao et al. (2007), Zang et al. (2012), Hakimzadeh and Mosahebi Mohammadi (2016), Kardan and Hakimzadeh (2018). However, for this research study, the momentary hydrodynamic forces acting on the piggyback pipelines due to steady currents have been investigated using numerical simulation. All simulations were performed in 3D using ANSYS FLUENT 16 software environment. First, the capability of the software for the current study was investigated. The number of cells and various turbulence models were considered to find the proper mesh size and model, respectively. Then, considering that for flows around a single pipe, the conventional turbulence models may not provide accurate results, therefore, by examining different cell types and turbulence models, an attempt was made to select the appropriate type that can provide more accurate results by spending a reasonable computational cost. Then, it was found that a structured cell formation together with LES turbulence model reproduced the flow patterns around the pipe with a reasonable accuracy when compared with the experimental data. For the numerical simulation results, first, the effects of the inlet flow velocity and main pipe diameter (i.e., the Reynolds number) variations on the coefficients of instantaneous hydrodynamic forces (i.e., drag and lift) exerted on piggyback pipelines were determined. Further, effects of the distance between pipes (G/D), the proximity to the bed (e/D) and the relative diameter (d/D) variations on the drag and lift coefficients were considered through computer simulations.

2. Methodology

2.1. Model geometry and meshing

A schematic diagram of the investigated model is shown in Fig. 1 (a, b). The flow passes through the pipe with diameter of D. In order to simulate the flow around the pipeline, a rectangular field with a length of 40D has been used, and the cylinder is placed at a distance of 16D from the channel entrance. To avoid from the wall effect on the results, the width and height of the calculation domain has been considered equal to 14D and 12D, respectively. The center of the pipe is intended as the center of the software coordinates.

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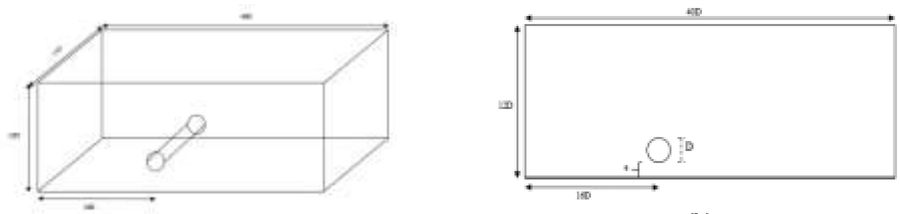


(a) (b)

Fig. 1. Schematic design of the investigated model: (a) 3D view, (b) 2D view.

2.2. Verification

In order to achieve an appropriate cell arrangement to ensure of the mesh independency, the sizes of computational cells at the upstream and around the pipe were considered large and small enough, respectively. For this purpose, for Reynolds number of 2×10^4, the models with different cells arrangement were produced and the results were compared with the results of Zhao et al. (2007). Table 1 shows the numerical simulation results for the drag and lift coefficients of a single pipe at this Reynolds number. It is observed that by reducing the cell size, the obtained numerical results for the hydrodynamic coefficients became more accurate and these coefficients for the C and D cell arrangements are closer to the results of Zhao et al.

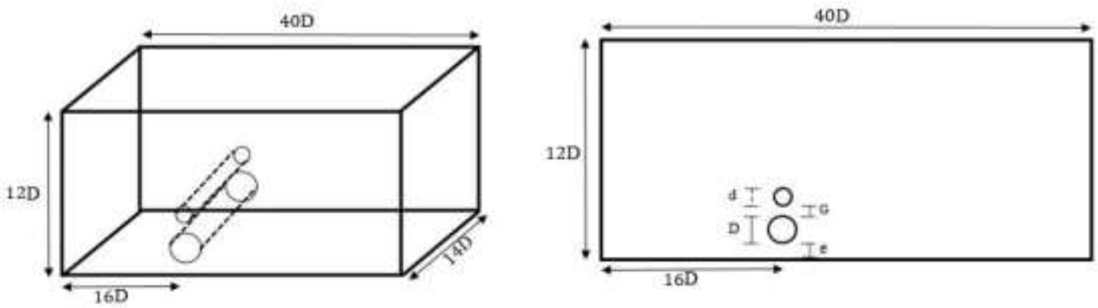
Table 1. Percentage error of the current results with the results of Zhao et al. (2007) for the drag and lift coefficients

Cell arrangement \ e/D ratio		0.1	0.2	0.3
Drag coefficients	A (large)	0.41	0.31	0.35
	B (medium)	0.24	0.19	0.22
	C (fine)	0.09	0.05	0.07
	D (very fine)	0.07	0.04	0.05
Lift coefficients	A (large)	0.57	0.61	0.45
	B (medium)	0.31	0.43	0.27
	C (fine)	0.12	0.15	0.10
	D (very fine)	0.11	0.13	0.09

3. Results and discussion

3.1. Base model

In order to simulate the flow around the piggyback pipelines, a similar rectangular domain with a length of 40D has been used, where the cylinders were placed at a distance of 16D from the channel entrance (Zhao et al., 2007). The center of the pipe was considered as the software coordinate center (Fig. 2).



(a) (b)

Fig. 2. Schematic view of the tested models: (a) 3D view, (b) 2D view

3.2. Effect of inlet flow velocity on the drag and lift coefficients

Effect of inlet flow velocity for the two ranges of Reynolds number (e.g., $8 \times 10^3 \leq Re \leq 2 \times 10^4$ and $1 \times 10^4 \leq Re \leq 2.5 \times 10^4$) was investigated. It was observed that, for the same period, with increasing the inlet velocity, the number (frequency) and amplitudes of fluctuations of the hydrodynamic force coefficients increased. Thereby, it may be found that at high flow rates, the probability of caused damage will be increased.

Also, it was found that with the accompaniment of the sub-pipe, the drag coefficient of the main-pipe decreased significantly. This reduction increased up to 40%, which basically would reduce the probability of damage in the main pipeline. Fig. 3 shows the variations of hydrodynamic force coefficients acting on the main and sub-pipes.

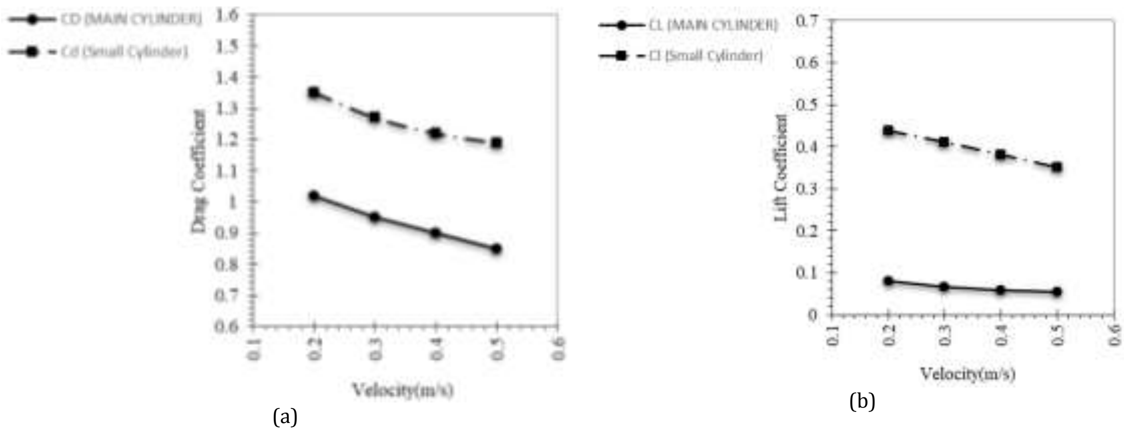


Fig. 2. Variations of the hydrodynamic force coefficients acting on the piggyback pipes for D=0.04m, G/D=0.2, e/D=0.2: (a) drag coefficient, (b) lift coefficient.

Then, it may be concluded that with increasing the inlet flow velocity, the time average values of the drag and lift coefficients for the main and sub-pipes decrease. The effect of inlet velocity on the drag coefficient of offshore pipes is small (i.e., about 10%), but its effect on the lift coefficient is noticeable. With increasing the inlet velocity from 0.2m/s to 0.5m/s, the time averaged value of the drag coefficient for the main pipe decreases by about 15%, while the time averaged value of the lift coefficient reduces by more than 30%. Also, for the small pipe, these changes for the time averaged drag coefficient is about 13% and for the time averaged lift coefficient is around 25%.

3.3. Effect of relative distance on hydrodynamic coefficients

In order to investigate the effects of the bed distance to the piggyback pipes on the hydrodynamic forces, the dimensionless parameter of the relative distance e/D is defined as the ratio of the distance of the pipe from the bed to the diameter of the main-pipe. In this research, relative distances of 0.1, 0.2, 0.3 and 0.4 were considered. Examining the time history of the main and sub-pipes drag coefficients at different distances showed that by reducing the relative distance, the fluctuation range of the coefficients of the hydrodynamic forces for the sub-pipe decreased significantly. With the addition of the sub-pipe, a significant reduction in the number of fluctuations and the amplitude of the fluctuations on the pipelines was observed, which reduces the probability of damage in the structure.

3.4. Effect of diameter of the main cylinder on the drag and lift coefficients

Finally, numerical results showed that with an increase in diameter of the main-pipe, the time averaged magnitudes of the coefficients for both the main and sub-pipes increased gradually. Compared to the time averaged values of the coefficients of hydrodynamic forces acting on a single pipe, a noticeable reduction of about 40% was observed in the time averaged values of the forces acting on the structure.

4. Conclusions

For this research study, the temporal hydrodynamic forces exerting on the piggyback pipelines due to steady currents have been investigated using a three dimensional numerical simulation tool. First, the capability of the software for the current study was examined. Then, it was found that for a single offshore pipeline, with increasing the gap between the pipe and bed, the fluctuation range of the drag and lift coefficients increased. Further, the time averaged value of the drag coefficient increased for the abovementioned variations, while the counterpart magnitude of the lift coefficient decreased. In pipelines with overlapping arrangement, the results showed that with an increase in fluid flow velocity, the number (frequency) and amplitude of fluctuations of the hydrodynamic forces coefficients acting on the pipes increased for the same period of time. Susequently, this may increase the probability of damage in structure.

With the addition of the sub-pipe, a significant decrease (i.e., up to 40%) in the time averaged values of the lift coefficients for the main pipe was observed, which has a significant effect on the reduction of the maintenance costs and serious damage of the structure.

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