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Multi-phase simulation of semi-submersible platform with pencil column using CFD

Multi-phase simulation of semi-submersible platform with pencil column using CFD

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Abstract. This paper reports based on a numerical study of multiphase fluid flow through a channel with a semi-submersible platform using computational fluid dynamics (CFD). The present study will be designing and analysing semisubmersible platform with pencil column and without pencil column. The computational fluid dynamics which solves simple differential equations and finite volume method (FVM) will be used. A turbulence model is considered i.e. large eddy simulation (LES). The semi-submersible model is designed as pontoons, columns, horizontal brace, pencil column and deck. The pontoons are horizontal placed stadium shaped structures which are submerged into the water. The columns are structures which connects the deck and pontoons. The horizontal braces are structures which connects the two or more columns which increases the rigidity of the columns. The pencil columns are columns with lesser diameter of about 0.25D which are placed between the columns. The deck are flat surfaces which provides workable area. This paper is a comparison of fluid flow by varying the model i.e. with and without pencil column in the semi-submersible platform. The velocity contours, pressure contours and streamline contours are plotted. The difference in pressure, velocity and streamline flow are tabulated and graphically represented. The percentage difference in pressure and velocity are calculated for structural design for various offshore platforms.

1. Introduction

A semi-submersible platform is an offshore platform or a marine vessel which are used in oil mines and other applications that are done in seas and oceans. These platforms play a major role offshore infrastructure like drilling rigs, heavy lift cranes etc. These semi-submersibles were found in 1960s for oil mines. Mostly the semi-submersibles are used in water depths higher than 520meters. The semi-submersibles are usually compared with drill ships. Compared to the drill ships, the semi-submersible provides for a better stability. There are many factors that may affect these structures such as lift and drag. This paper is an experimental study which compares the semi-submersible design with and without a semi-submersible using computational fluid dynamics.

Sadeghi et al, [1] performed experiments in designing semisubmersible platforms with pencil columns and analyzing the effect of fluid flow. Ma et al, [2] performed analyzing the structural dynamic responses of the semisubmersible platform in sea states under the combined wind/wave loads using Computational Fluid Dynamics (CFD). Raed et al, [3] performed Weibull distribution for wave height and log-normal distribution in the zero-up crossing period and inverse first order reliability Method and also the direct Monte Carlo Simulation. Alimuddina et al, [4] performed experiments in predicting the motion of a Semi-submersible and analyzing the motion of the semi-submersible platform. Liu et al, [5] performed experiments for semi-submersible floating offshore wind turbines. Zhong et al, [6] performed experiments in analysis of motion of semisubmersible in sea waves. R. T. Goncalves et al, [7][8] performed experiments on vortex-induced motions with four square columns in a semi-submersible platform. Emami and Gharabaghi [9] performed experiments using poroelastic layers using motion response reduction method in a semi-submersible platform. Choi et al, [10] performed coupled motion analysis of a semi-submersible system in tension leg platform.

Ghafari and Dardel [11] study on catenary mooring system of the semi-submersible platform with a dynamic response. Karimirad and Michailides [12] performed alternate concept for wind technology based on v -shaped semisubmersible offshore for wind turbine. Liu et al, [13] performed various experiments on designing loads for semisubmersible platform to support wind turbines. Mao and Yang [14] investigated on deep draft for parametric pitch instability on an irregular wave. Mas-Soler [15] performed the motions of a semi-submersible to estimate by on-site wave spectra. Qiu [16] used algorithm based on surrogate model for multiple objective optimizations for a semi-submersible platform. Servan-Camas et al, [17] validation on semi-submersible platform using second order time depended FEM model. Tie-bing et al, [18] experimentally investigated on semisubmersible platform for wave run-up characteristics which was conducted along the column and air gap response. Tran and Kim [19] [20] used coupled dynamic response computation for a floating wind turbine placed on a semisubmersible platform. Travanca and Hao [21] performed on floating production systems to control wave induced vibrations. Wang et al, [22] performed experiments based on hydrodynamic performance on semisubmersible platforms having a non symmetrical pontoon.

The objective of the paper is investigating the multi-phase turbulent flow around a semi-submersible platform. The model is placed inside a channel and multi-phase fluid flow air and water is simulated. The model chose for the simulation is large eddy simulation model. The velocity magnitude for the phases is given as 10m/s. The numerical simulations are performed by using a simple differential equation and Finite Volume Method (FVM). The enclosure is considered to be fluid medium and also two phases are used air and water. The results for pressure and velocity are simulated and found at specific locations.

Two models are considered for the experiment one is with pencil column and other without pencil column. The percentage difference between pressure and velocity for both the models are tabulated. The average percentage difference is calculated for both the models. The various contour of velocity, pressure and the streamline flow are found and represented in figures. Thus, several governing parameters are investigated and the flow characteristics are analysed.

2. Methodology

The semi-submersible model consists of pontoons, columns, horizontal brace, pencil column and deck as shown in the figure 1. The pontoons are horizontal structures which placed at the bottom which is totally submerged into the waters. The columns are vertical structures which withstand the semi-submersible platform and also connects the deck to the pontoons. The horizontal braces are structures which connects the two or more columns. The pencil column [1] is similar to the columns but dimensional different with about 0.25 diameter of the columns. The deck are surfaces upon which works takes place and where all the humans, machinery and other equipment's are placed. The model used in the present study is of 160m long, 90m wide and 40m high semi-submersible and two models are designed with and without pencil column. The model is centrally placed inside a channel through which multi-phase fluid is simulated along the x-direction. The type of solver used pressure-based and absolute velocity formulation is used. A turbulence model is used and large eddy simulation with Smagorinsky-Lilly is considered. The boundary conditions along x -axis at the inlet is Velocity-inlet and the outlet is pressure-outlet. The residual for continuity, x-velocity, y-velocity and z-velocity is considered to be 0.001. The velocity magnitude in the x-direction is set to be 10m/s. The numerical simulations are performed by using a Finite Volume Method (FVM). The turbulent flow is considered for the model by solving the large eddy simulation (LES) equation for different velocity.

2.1 Governing equations

The governing equations following are used to model the semi-submersible:

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$$\frac{\partial \overline{u_i}}{\partial t} + \frac{\partial \overline{u_i}}{\partial x_i} = 0 \tag{1}$$

$$\frac{\partial \overline{u_i}}{\partial t} + \overline{u_j}\frac{\partial \overline{u_i}}{\partial x_j} = -\frac{1}{\rho}\frac{\partial \overline{p}}{\partial \overline{x_i}} + \frac{\partial}{\partial x_j}\left[\upsilon \frac{\partial \overline{u_i}}{\partial x_j} - \overline{u_i' u_j'}\right] \tag{2}$$

$$\frac{\partial \overline{T}}{\partial t} + \overline{u_i}\frac{\partial \overline{T}}{\partial x_i} = \frac{\partial}{\partial x_i}\left[\alpha \frac{\partial \overline{T}}{\partial x_i} - \overline{u_i' T'}\right] \tag{3}$$

$$\frac{\partial k}{\partial t} + \overline{u_i}\frac{\partial k}{\partial x_i} = \frac{\partial}{\partial x_i}\left[\frac{\upsilon_t}{\sigma_k}\frac{\partial k}{\partial x_i}\right] + \upsilon_t\left[\frac{\partial \overline{u_i}}{\partial x_j} + \frac{\partial \overline{u_j}}{\partial x_i}\right]\frac{\partial \overline{u_i}}{\partial x_j} - \varepsilon \tag{4}$$

$$\frac{\partial \varepsilon}{\partial t} + \overline{u_i}\frac{\partial \varepsilon}{\partial x_i} = \frac{\partial}{\partial x_i}\left[\frac{\upsilon_t}{\sigma_k}\frac{\partial \varepsilon}{\partial x_i}\right] + C_{1\varepsilon}\frac{\varepsilon}{k}\upsilon_t\left[\frac{\partial \overline{u_i}}{\partial x_j} + \frac{\partial \overline{u_j}}{\partial x_i}\right]\frac{\partial \overline{u_i}}{\partial x_j} - C_{2\varepsilon}\frac{\varepsilon^2}{k} \tag{5}$$

Where ‘ρ’ indicates the density of fluid and ‘u’ represents the velocity and ‘k’ & ‘ε’ indicates the kinetic energy and dissipation fields

2.2 Geometry and Specifications

The semi-submersible dimensions are of total Height ‘H’ = 40m and total length ‘L_1’ = 160m as shown in figure 2. The diameter of the column in the semi-submersible is denoted as L_c = 10m and height of the column is denoted as H_c = 25m as shown in figure 2. The length of the semi-submersible ‘L_2’ = 90m and the length of pontoons is equal to the length L_1. The height of the pontoon H_p = 10m as shown in figure 3. The length of the horizontal brace L_b = 60m and diameter of the column H_b = 5m as shown in the figure 3. The diameter of the pencil column is 0.25L_c which is 2.5m. The model is created using solid works and imported into designer modeler in ANSYS workbench. The fine meshing was done using fluent.

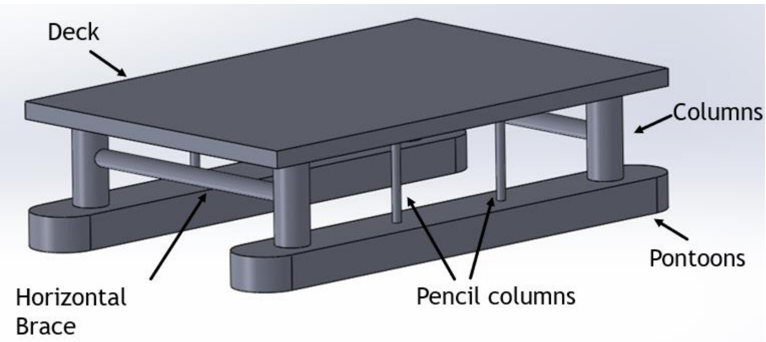

Figure 1. 3D.representation.of the model

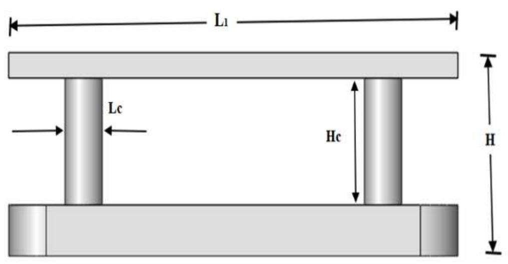

Figure 2. 2D representation of model side view

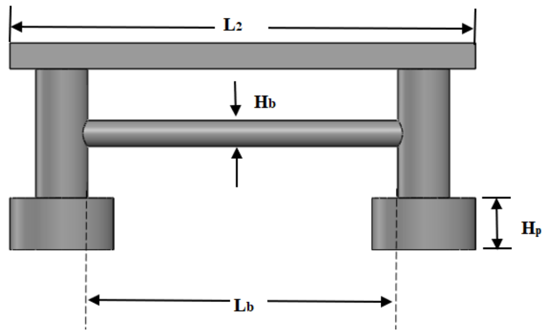

Figure 3. 2D representation of model front view

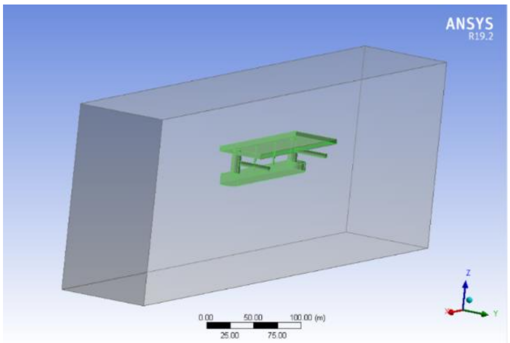

Figure 4. Geometry in designer modeler

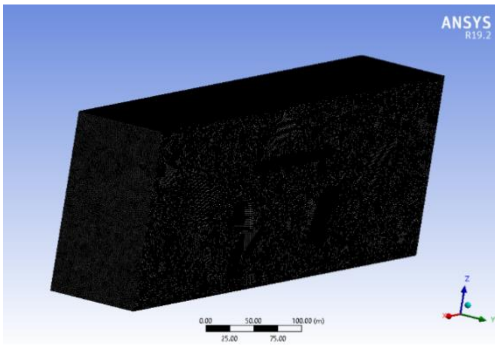

Figure 5. Structured mesh of the model

The details of the mesh are 811989 number of nodes and 4416070 number of elements are created. The only model half of the model is considered since the geometry is symmetric for the simulation. The main outcome of this paper is the design and analysis of semi-submersible platform using computational fluid dynamics. The necessary boundary conditions are given at all boundaries to solve with pressure-based model. The simulation is done for a multiple time. The transient pressure-based model was used. The gravity was set along the z-axis and large eddy simulation with smagorinsky lilly was considered. A multi-phase model water and air, with free surface level 30m & bottom level -100m considered to be water and the other region set to air. The velocity magnitude is set to 10m/s as inlet and outlet as pressure outlet. The simulation is done by varying the model with pencil column and without pencil column.

3. Results and Discussions

The velocity, pressure, streamline is resulted. The variation in the model is simulated with velocity as 10m/s. The velocity contour of semi-submersible without pencil is shown in fig 6 and fig 7. The velocity contour of semi-submersible with pencil is shown in the figure 8 and figure 9. In fig 10, shows the top view of velocity contour of semi-submersible without pencil. In fig 11, shows the top view of velocity contour of semi-submersible with pencil. The Pressure contour of semi-submersible without pencil is shown in fig 12 and the pressure contour of semi-submersible with pencil fig 13. The results are saved for every 50 iterations and to about 1500 iterations are taken are every variation. The fluid flow is studied and recorded. The streamline and vector of semi-submersible without pencil is shown in fig 14 shows the fluid flow. The streamline and vector of semi-submersible with pencil is shown in fig 15 shows the fluid flow.

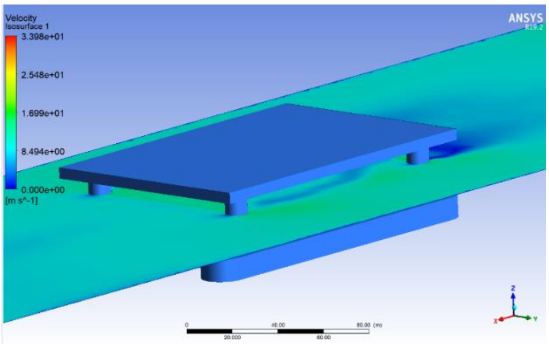

Figure 6. Velocity contour of model without pencil column along (-) x axis

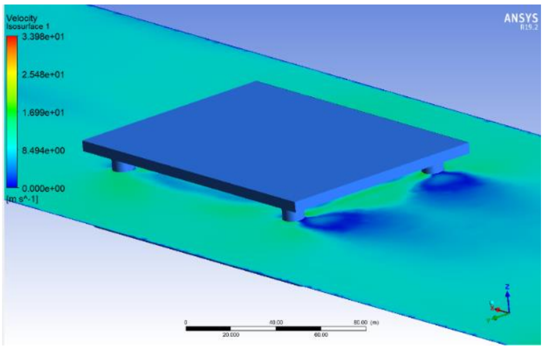

Figure 7. Velocity contour of model without pencil column (+) x axis.

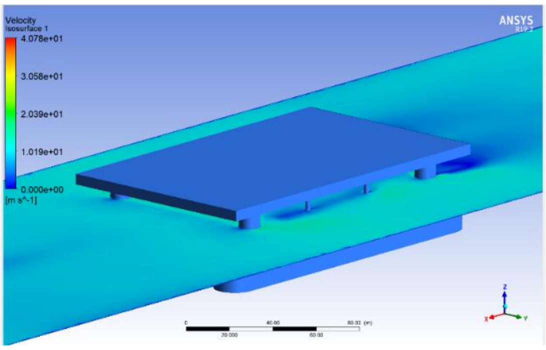

Figure 8. Velocity contour of model with pencil column (-) x axis

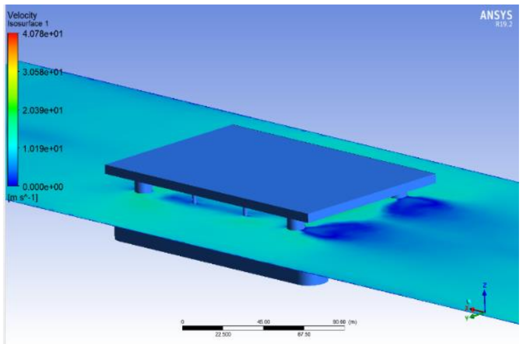

Figure 9. Velocity contour of model with pencil column (+) x axis

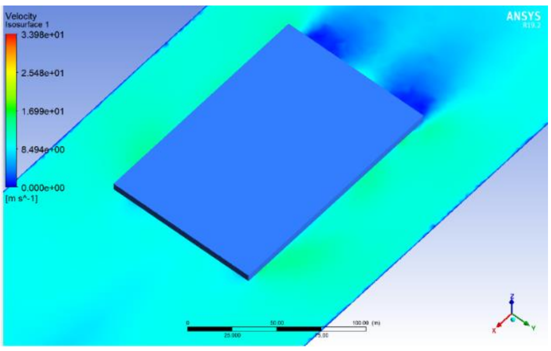

Figure 10. Velocity contour of model without pencil column along z-axis

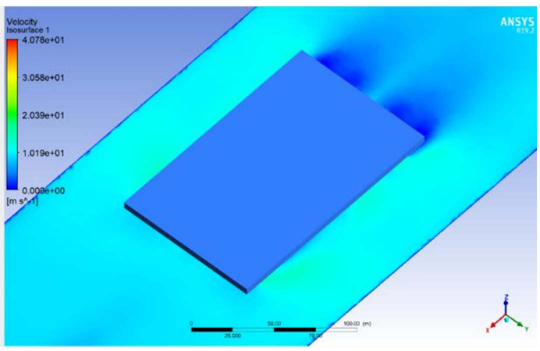

Figure 11. Velocity contour of model with pencil column along z-axis

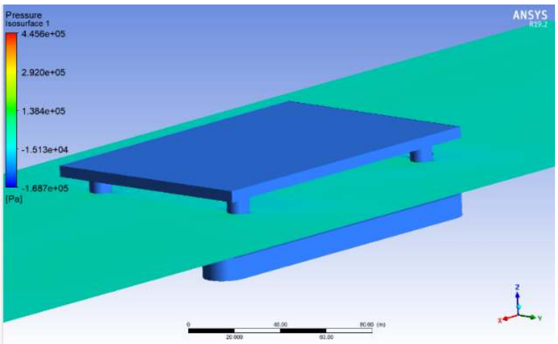

Figure 12. Pressure contour of model without pencil column

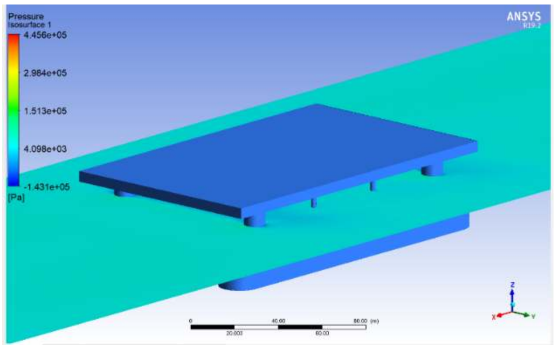

Figure 13. Pressure contour of model with pencil column

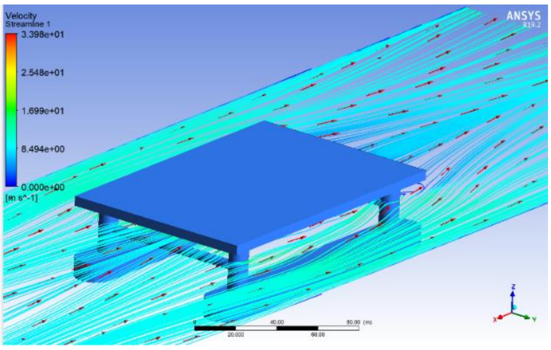

Figure 14. Streamline contour of model without pencil column

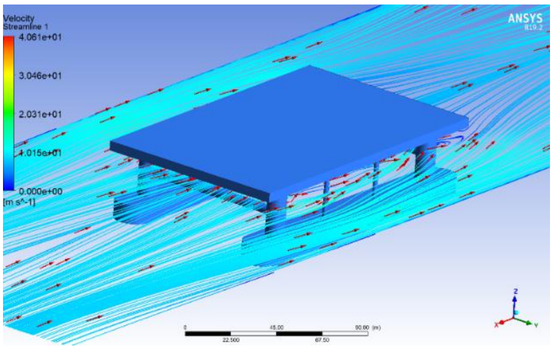

Figure 15. Streamline contour of model with pencil column

The figure 16 is a graphically representation of velocity difference between the two models i.e. with and without pencil column. The coordinates x-axis is varied from 50 to -50 where the y-axis and z-axis are kept constant as -40 and 27 respectively. The velocity and pressure values are noted at several intervals which are tabulated in table 1. (Note- values are considered between the columns) The velocity tends to increase at vicinity column when a pencil column is placed. The figure 17 is a graphically representation of pressure difference with and without pencil column.

Similar X, Y, Z co-ordinates are considered which was taken in the velocity difference. Equal interval of 10 meters are taken and the results are noted as shown in table 1. The pressure and velocity behind the column are comparatively less and further increases along the x-direction without a pencil column. To reduce this effect pencil columns are modelled which improve significantly. The red & delta symbolled line represents without pencil column and blue & circle symbolled line represents with pencil column. The percentage difference in pressure and velocity are calculated to give references for structural design for offshore platforms as shown in table 2.

Table 1. Variation of pressure and velocity along x-axis.

X-Axis	Without pencil column		With pencil column	
	Pressure (Pa)	Velocity (ms^{-1})	Pressure (Pa)	Velocity (ms^{-1})
50	-10.302	9.84012	-6.854	10.2527
40	-12.751	7.13313	-10.711	4.51317
30	-13.295	5.81811	2.336	3.55969
20	10.269	6.14242	12.467	2.4564
10	10.807	6.55059	9.453	5.1781
0	11.319	6.63156	11.647	6.15168
-10	11.699	6.72464	13.712	6.05409
-20	8.886	7.57207	9.054	2.5564
-30	10.330	10.5861	8.064	9.6538
-40	16.788	11.4099	12.942	10.3273
-50	41.288	8.50886	37.170	7.78874

Table 2. Difference in pressure & velocity in x-axis.

X-Axis	Difference in pressure (%) (Pa)	Difference in velocity (%) (ms-1)
50	40.19	4.11
40	17.39	44.99
30	285.26	48.17
20	19.33	85.73
10	13.37	23.40
0	2.86	7.51
-10	15.84	10.49
-20	1.87	99.04
-30	24.64	9.21
-40	25.87	9.96
-50	10.50	8.84
Average	41.56	31.95

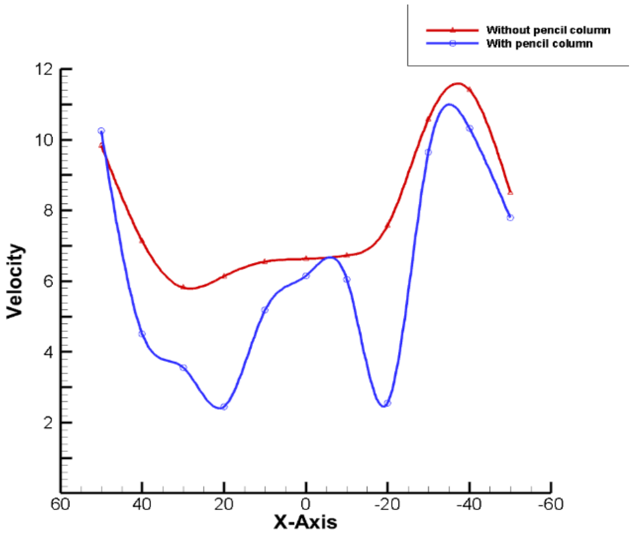

Figure 16. Graphically representation of velocity difference

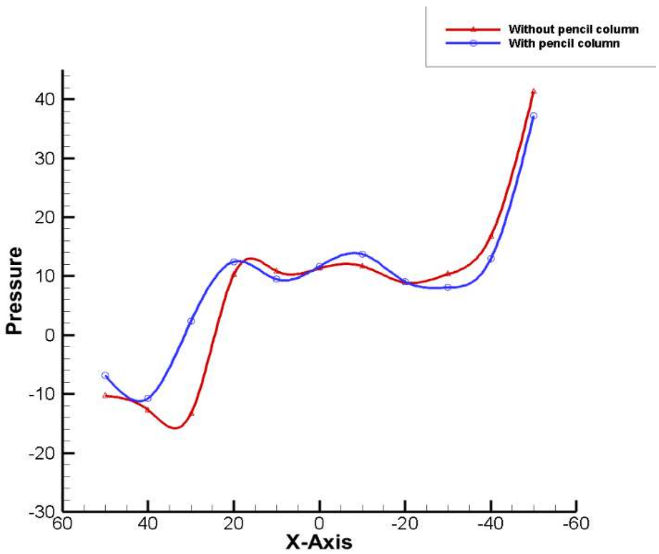

Figure 17. Graphically representation of **p**ressure difference

4. Conclusion

The fluid flow characteristics across a semi-submersible platform through a channel are numerically studying various model of semisubmersible. The turbulent flow approach using LES is modelled and also the governing equations are discretized by using FVM. The stream line contours, velocity contours and pressure contours are plotted for different models. The stream line and vectors indicated the flow direction of the fluid through open channel. The pressure and velocity behind the columns comparatively less and further increase along the x-direction without a pencil column. To reduce this effect pencil columns are modelled which improve significantly. The velocity difference slightly reduces at the vicinity of the column when pencil columns are used. The results obtained from the present study will provide a suitable data for designing semi-submersible platforms with pencil column which can be used in offshore applications.

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