NUMERICAL SIMULATION OF VISCOUS SHEAR FLOW AROUND TANDEM CYLINDERS

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1 INTRODUCTION

Marine Technology as a knowledge can be applied on several projects and problems. The project run by the Norwegian Public Road Administration (NPRA) introduces the Coastal Highway E39, better known as Ferry Free E39.

The goal of Coastal Highway is to establish fixed links between the fjord-crossings and decrease traveling time across Western Norway.

This Master Thesis studies and analyzes the effects of a shear current flow on the proposed fjord-crossing concept, Submerged Floating Tube Bridge (SFTB).

Figure 1.1: Coastal Highway E39 runs along Western Norway from Kristiansand to Trondheim.

2 METHOD

The analysis is performed numerically with use of the open source program OpenFOAM. The SFTB is simplified as tandem cylinders with diameter (D) equals to 1 and span-wise length of 6D. The longitudinal gap between the tandem cylinders are L/D=3.2, which is the same gap used to dimension the SFTB presented in figures (2.1) and (2.2).

The inlet velocity U(y) (Eq. 2.3) is a shear current with Uc=0.5 and a gradient G=0.1 (Eq. 2.4) in figure (2.3). The inlet velocity at the bottom boundary will be zero, while the inlet velocity at top boundary is 1.0. The shear ratio is K=0.2 (Eq. 2.2), where the flow is simulated for Reynolds number 500 with a laminar flow solver.

This Master Thesis will focus on studying the hydrodynamic effects of a current shear flow around tandem cylinders.

Drag-and-lift coefficients are analyzed, oscillation periods, frequencies and Strouhals numbers are obtained.

Plots of velocity magnitude, pressure distribution and distribution of vorticity in z-direction are found the the flow problem where a shear current is subjected on 3D tandem cylinders.

The Finite Volume Method is used to solve the Navier-Stokes equation (Eq. 2.1). The computational domain, boundary conditions and the grid are made to solve the flow problem with respect to boundary layer resolution around and in-between the tandem cylinders, and visualizing the flow phenomena occurring in the wake region.

The computational domain is constructed in the meshing program MEGA, where the 2D mesh is presented in figure (2.4).

$$\frac{\mathrm{D}U_i}{\mathrm{D}t} = -\frac{1}{\rho}\frac{\partial P}{\partial x_i} + \nu\left[\frac{\partial^2 U_i}{\partial x_j x_j}\right] + f_i$$

Equation 2.1: Navier-Stokes equation

$$K = \frac{GD}{U_c} = \frac{U_A - U_B}{U_c}$$

Equation 2.2: Shear Rate K

$$U(y) = U_c|_{y=0} + Gy$$

Equation 2.3: Shear inlet velocity

$$G = \frac{\mathrm{d}U}{\mathrm{d}y} = \frac{U_A - U_B}{D}$$

Equation 2.4: Shear flow gradient G

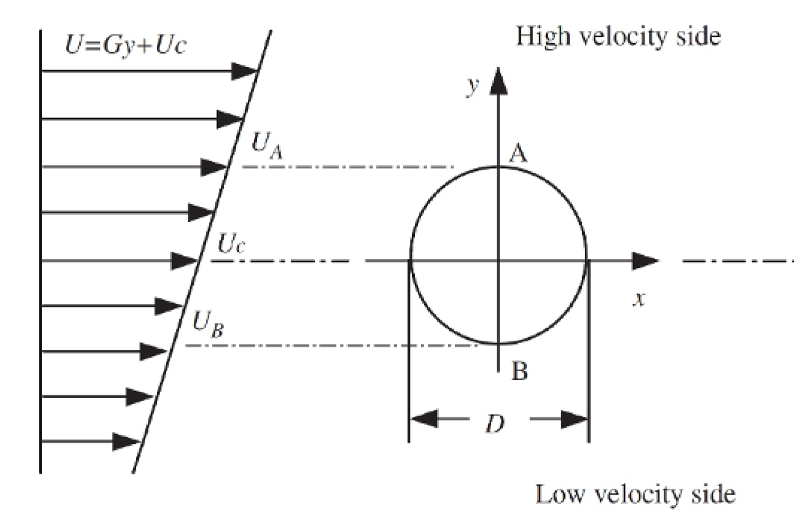

Figure 2.3: Planar shear flow around a circular cross-section.

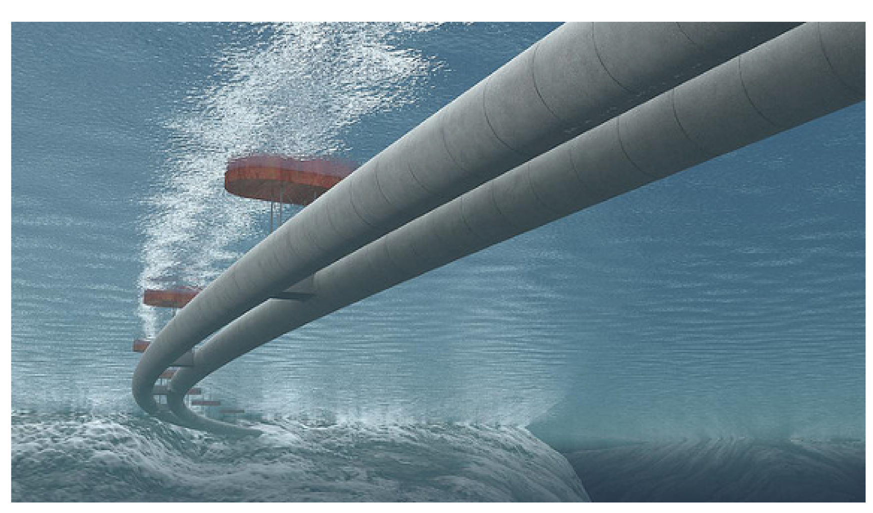

Figure 2.1: Submerged Floating Tube Bridge seen from underwater perspective with pontoons.

Figure 2.2: Submerged Floating Tube Bridge seen from underwater. Illustrating the tunnel inside the submerged cylinder.

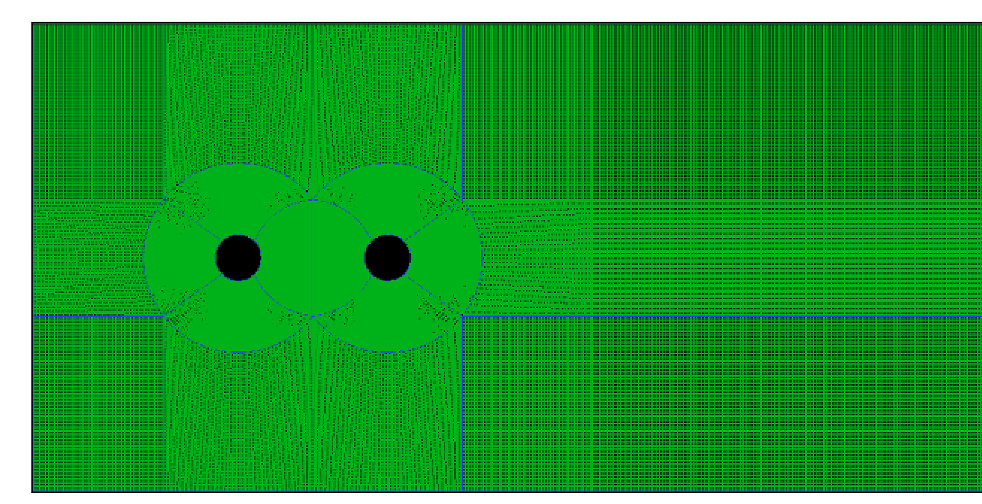

Figure 2.4 Mesh used to analyze the sef fect of shear flow around tandem cylinders. The mesh is made in MEGA.

3 RESULTS

Subjecting a shear current flow on tandem cylinders at Reynolds number 500, the drag and lift forces around the cylinder will oscillate around a mean value. The oscillation periods, frequencies and Strouahls number are presented in the table below:

-	Upstream	Downstream
mean C_L	-0.12319	-0.07862
mean C_D	1.02754	-0.15829
RMS C_L	0.01325	0.39875
RMS C_D	0.00838	0.14509
$T_v[s]$	(5 & 9.804)	13.89
$f_v[Hz]$	(0.2 & 0.102)	0.072
S_t	(0.4 & 0.204)	0.144

The lift forces around both upstream and downstream cylinder are expected to oscillate close to zero. The drag force for the upstream cylinder is Cd = 1.027, while the downstream cylinder experiences a drag force oscillating close to zero.

Meneghini et al. (2001) and Ding et al. (2007) presents how the drag force of the downstream cylinder is suppose to change from Cd < 0 to Cd > 0, when L/D > 3 for tandem cylinders in uniform flow. The results obtained for a shear flow problem, is a negative drag force which is close to zero.

The velocity fluctuation behind the downstream cylinder oscillates with a period Tv = 13.89s and a frequency fv = 0.072 Hz. The Strouhals number is 0.144. The upstream cylinder will have small velocities fluctuating around zero. The periods and frequencies obtained from Power Spectral Density curves with respect to velocity fluctuations are not ideal since the velocities are close to zero.

The velocity magnitude in figure 3.1 visualizes how there are approximately no velocities in-between the tandem cylinders. Both velocity magnitude and pressure distribution (fig 3.2) presents stagnation point and vortex shedding downstream.

The distribution of vorticity in z-direction (fig 3.3) will visualize the flow behavior downstream and three-dimensional effects that occur along the span-wise length of the cylinder.

Analyzing a Shear Flow around Tandem Cylinders, one must understand the effects of having tandem cylinder, instead of a single submerged cylinder. The effect of shear current flow versus a uniform flow is discussed in the Master Thesis.

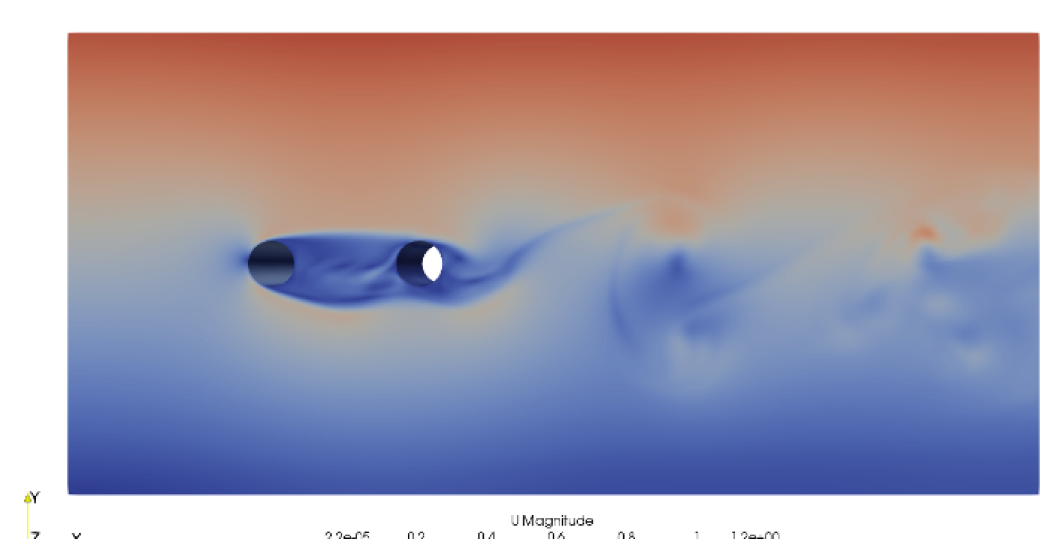

Figure 3.1:Velocity magnitude. At time instant t=500s..

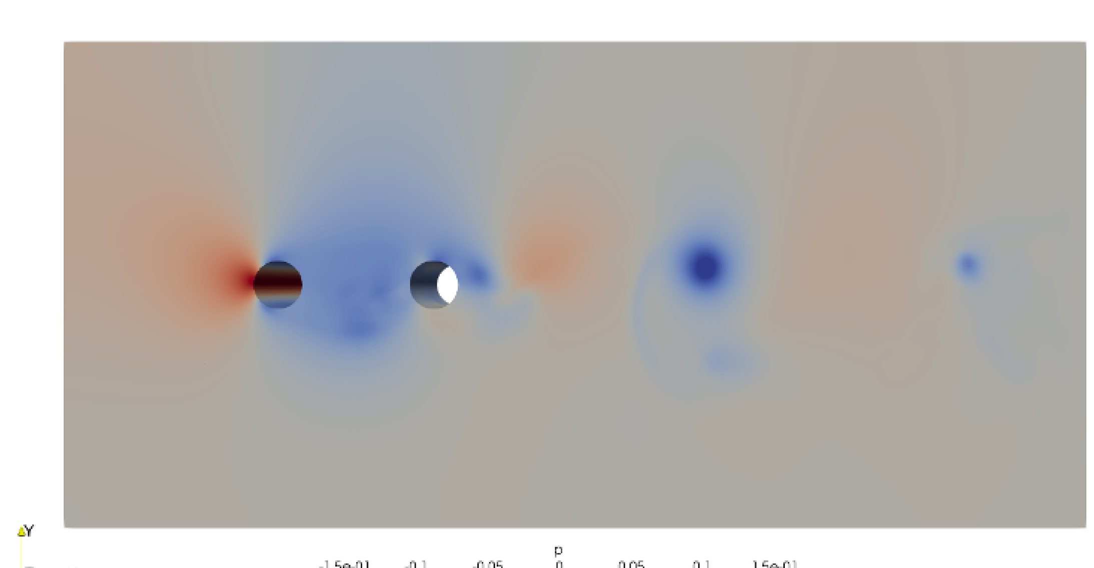

Figure 3.2: Pressure distribution. At time instant t=500s..

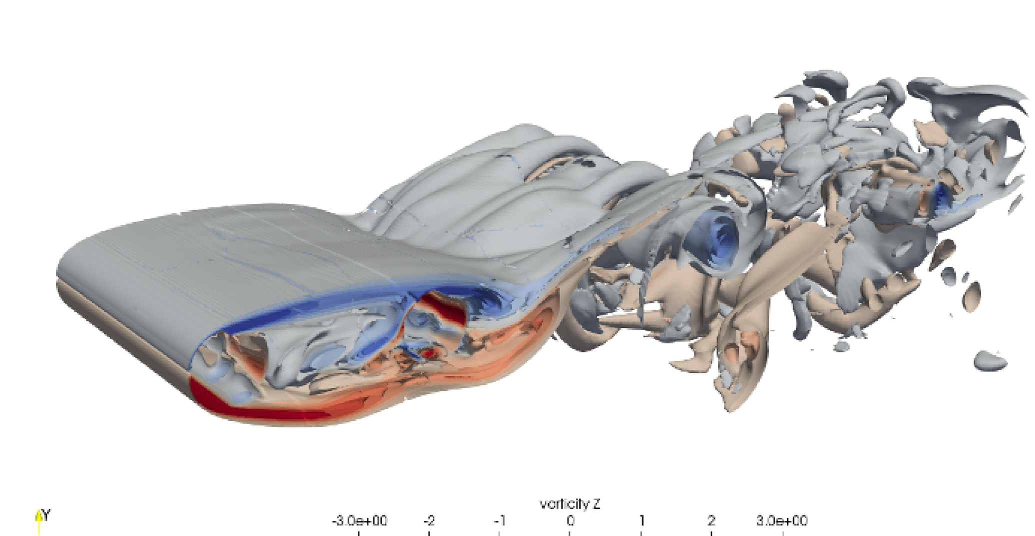

Figure 3.3: Distribution of vorticity in z-direction. At time instant t=500s..

4 FUTURE WORK

Coastal Highway E39 is a 20 year long project where all fjord-crossings are supposed to be replaces with fixed links. The concept of a Submerged Floating Tube Bridge (SFTB) combines offshore technology in terms of vertical stiffness in mooring lines and pontoons. The knowledge behind hydrodynamic loads and fatigue of the SFTB are important when creating a bridge which submerges 30 m under the fjord surface.

The analysis performed in this master thesis simplifies the SFTB as two straight and parallel cylinders with span-wise length of 6D. The numerical simulation is performed with a laminar solver at Reynolds number 500.

In the future the analysis can be extended to tandem cylinders in turbulent shear flow, and extending the span-wise length or changing the longitudinal gap. The tandem cylinders could also be analyzed with a slight curvature along the span-wise length with fixed ends, as the SFTB enters solid land and islands.

The current load can be changed in terms of how the velocities are changing with the depth. Does the current have linear profile or should one use another profile? The Submerged Floating Tube Bridge will have less effect of wind as it is submerged under water, but the effects of waves can also be added with the current velocity.

Marine technology and the knowledge obtained from the department can be used in several interdisciplinary project as in the Coastal Highway E39.

5 REFERENCES

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