REDUCING THE DRAG ON A CIRCULAR CYLINDER BY UPSTREAM INSTALLATION OF CYLINDER TYPE-I AND DOWNSTREAM INSTALLATION OF ELLIPSE CYLINDER

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Abstract

Various forms and number of passive control have been investigated in order to minimize the drag coefficient received by circular cylinder. Thus, the strength of circular cylinder construction can be maintained longer. In this study, a circular cylinder with two passive controls are the first passive control fix be a cylindrical type-I is placed in front of the cylinder

at distance ratio $S/D = [0.6, 3.0]$ with difference 0.6, while the second passive cylinder compares the ellipse and horizontal type I which is placed behind the cylinder at a ratio of distance $T/D = [0.9, 2.1]$ with difference 0.3. The flow across the circular cylinder with two passive controls in Reynolds 5000 is solved by numerically using the first order finite difference method with the third order error and second order finite difference method with second order error. Differences of second passive control geometry and variation of distance of S / D and T / D have effect on drag coefficient obtained. The minimum drag coefficient is obtained at the distance S / D = 1.8 and T / D = 1.5, using second passive control of the ellipse or horizontal type I cylinder. However, the comparison results that the second passive control of the elliptical shape minimizes the drag coefficient by up to 39% against the cylinder without control. Mathematical model of drag for circular cylinder with passive controls cylinder type I and ellipse is $E(x, y) = 0.5285 + 0.7314y + 0.1675y + 1.6517x - 2.2506xy + 0.5074xy^2 - 0.5398x^2 + 0.8142x^2y - 0.1847x^2y^2$.

This model can be used to find the drag coefficient on S/D and T/D directly and easier.

Keywords

Reducing the drag, Mathematical model of the drag, I passive control, Ellipse passive control.

1. Introduction

In the field of building infrastructure such as bridges, the bridge pile is an important component to hold the load received by the bridge. Strong bridge pile can be constructed by quality materials and able to withstand the effects of external damage such as the fluid passing around the bridge pile. The bridge pile will receive a drag from the fluid flow that affected on the resistance of the pile. The drag must be minimized so the pile strength can last long. This is very important because it relates to the safety user.

Drag can be reduced by modifying the geometry of the object or by giving passive control around the object. Research on the fluid flow through a single object such as the cylinder shape (A.O. Ladjedel & Imine, 2011), the square shape (Song & Park, 2009) and the ellipse shape (M. Sudharsan & Tiwari, 2010). Then modify the geometry of objects such as cylinders into shapes I and D with different cutting angles (Igarashi & Shiba, 2006). The cylinder is modified by cutting the front side become type-D shape and cut the front and back side become type-I. The D and I shape are cut at an angle of $50° - 53°$ with Reynolds

$\mathrm{Re} > 2.3 \times 10^4$. The result of simulation is width of wake decreases and the vortex formation goes downstream. While the drag received object can be reduced almost 50%. Other studies are still related to the geometry of cylindrical objects of type I and type D. But the object is used as a passive control that is placed in front of or behind the main object. The cylindrical passive control of type I is placed in front of the circular cylinder at the distances ratio $0.6 \leq S/D \leq 3.0$(Imron et al., 2013). The aim is to obtain an optimal passive control position that resulted in the smallest drag. In addition to observing the effect of distance ratio, also observe to variations of Reynolds numbers are Re = 7000. In order to obtain drag at the desired distance ratio interval, the drag calculation is performed only at some point in the distance ratio. Then construct a mathematical model of the drag coefficient. So, drag can be obtained in every point S/D that needed. On the other hand, several other studies related to passive control and circular cylinder have been done is the plate passive control arranged in parallel behind the cylinder (Bao & Tao, 2012), two small cylinder behind the cylinder (Kuo & Chen, 2009) and multiple rods around the main cylinder (Lin Lu, et al., 2014).
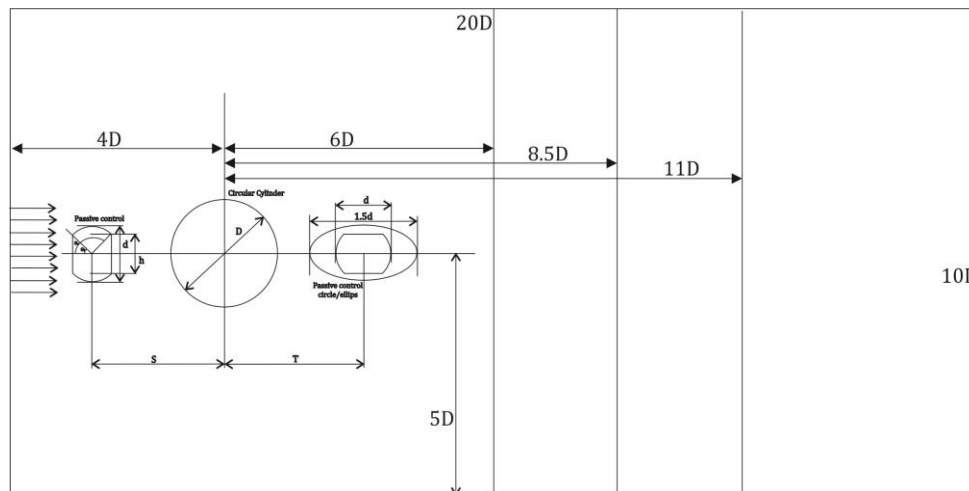
Figure 1: *Design of fluid flow field with passive control scheme*

In this study, the circular cylinder uses two passive controls on Reynolds 5000. The first passive control uses a type I cylinder and the second passive control is investigated in the form of passive control that drag can be reduced significantly. The passive control form that is compared is the cylindrical shape of type I horizontal position and ellipse form. Then resolved numerically and simulated based on the system as in figure 1. The area of simulation is

$20D \times 10D$. The circular cylinder center is located at $(4D, 5D)$ and the first passive control is placed in front of the cylinder at the distance ratio (S/D), the second passive control is placed behind the cylinder at the distance ratio (T/D). Fluid flow characteristics are known by observing the wake occurring at a distance of 6D, 8.5D and 11D from the behind of circular cylinder.

2. Numerical Method

The Incompressible, unsteady Navier-Stokes equations and continuity equations form are (Imron et al., 2013):

$$\frac{\partial \mathrm{u}}{\partial \mathrm{t}} + \mathrm{u}.\nabla \mathrm{u} + \nabla \mathrm{p} = \frac{1}{\mathrm{Re}} \nabla^2 \mathrm{u} \qquad (1)$$

$$\nabla.\mathrm{u} = 0$$

Where u is the flow velocity component, Re is the Reynolds number and p is the pressure component. The Navier-Stokes Equation solved by numerical method using finite difference method and following the step of the SIMPLE (Semi-Implicit Method for Pressure Linked Equations) algorithm. The SIMPLE Algorithm can be shown in figure 2.

The first step discretization of differential equation, we're using staggered grid. Every component put on different point. Pressure component at the point (i,j), x-velocity component at the point (i+0.5,j) and y-velocity component at the point (i,j+0.5). Then, differential equation discriminated by first order with third order error and second order with second order error. The form of discretization for differential equation as follows:

$$\left(f_x\right)_i = \frac{2f_{i+1} + 3f_i - 6f_{i-1} + f_{i-2}}{6dx} \qquad \left(f_y\right)_j = \frac{2f_{j+1} + 3f_j - 6f_{j-1} + f_{j-2}}{6dy}$$

$$\left(f_{xx}\right)_i = \frac{f_{i+1} - 2f_i + f_{i-1}}{dx^2} \qquad \left(f_{yy}\right)_i = \frac{f_{y+1} - 2f_y + f_{y-1}}{dy^2}$$

After discretization, follow the procedure of SIMPLE algorithm. Firstly, give the initial value to each component. Then solve the momentum equation to get velocity component of fluid flow. Momentum equations can be written by equations (1) without pressure component.

$$\frac{\partial \mathrm{u}}{\partial \mathrm{t}} + \mathrm{u}.\nabla \mathrm{u} = \frac{1}{\mathrm{Re}} \nabla^2 \mathrm{u} \qquad (2)$$

Then pressure component can be got by pressure-correction equation.

$$\nabla^2 p = \frac{1}{\Delta t} \nabla u * \qquad (3)$$

Convergence of pressure-correction solution will be more quickly filled by using SOR (Successive over Relaxation) method. SOR method can be written :

$$\left(p_n\right)_{i,j} = \left(1-\omega\right)\left(\left(p_{n-1}\right)_{i,j}\right) + \omega\left(p_n\right)_{i,j}$$

and choosing $\omega > 1$ (Carroll, 2011). And the last step is make visualization of the component value obtained.
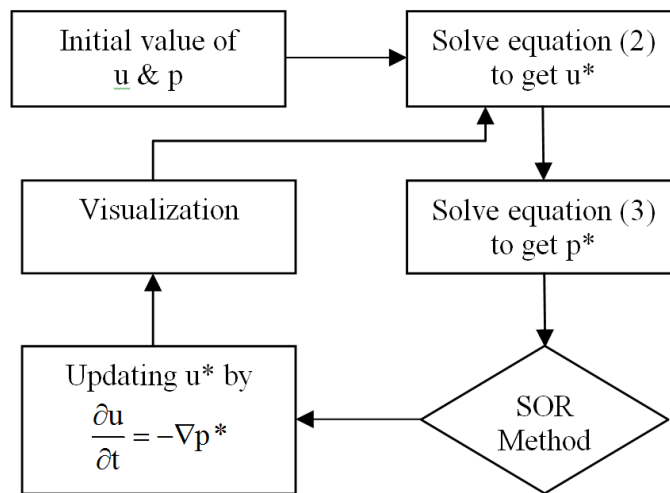

Figure 2: *SIMPLE Algorithm*

3. Result

The fluid flow in the circular cylinder with two passive controls is simulated on the 20Dx10D field as shown in figure 1. The first passive control is simulated at the distance ratio $S/D = 0.6, 1.2, 1.8, 2.4$ and 3.0 in front of cylinder and the second passive control is simulated at the distance ratio $T/D = 0.9, 1.2, 1.5, 1.8$ and 2.1 behind the cylinder. The variation of the passive control distance ratio with the cylinder aims to observe the effect of the distance ratio to the drag coefficient of cylinder. Furthermore, the fluid flow profile is known from the wake profile at a distance of $6D, 8.5D, 11D$ from the centre of circular cylinder.

3.1 Validation Code

The Navier-Stokes equation was used to solve the fluid case in this investigation. Solution of the Navier-Stokes equation is obtained numerically with the help of computer code. To find out the accuracy of result using computer code, we identify based on the calculation of drag received by the circular cylinder without passive control with Reynolds 100. Validation is done by comparison of drag calculations that obtained by the other researchers. The results are shown in table 1.

Table 1: *Comparison of drag coefficient with the other research*

| Re	Author	Zulh*	Lima**	Ding***
100	1.35837	1.4	1.39	1.356

*(Noor et al., 2009)

**(Silva et al., 2003)

***(Ding et al., 2007)

Based on the table 1, the results of the calculation drag coefficient obtained is not much different from the other researchers. Thus, the computer code that has been created can be used for simulation in this investigation.

3.2 Wake

Based on numerical simulation results, it is known that in the circular cylinder boundary layer, the separation point appears on the top of the cylinder and the bottom of the cylinder. The wake region is between the cylinder boundary separation points. The fluid flow velocity profile is taken at a distance of $6D, 8.5D, 11D$ from the centre of circular cylinder which is still in the wake effect region.

In the figure 3, shows a fluid flow velocity profile passing through a circular cylinder with a cylindrical passive control of type I and an ellipse. The velocity profile of figure 3a shows the speed distribution of the wake region at a distance of 6D measured from the center of the circular cylinder. The results show that at the distance ratio T/D = 1.5 has a wake area that is narrower than the wake area at T/D = 0.6. Whereas in figure 3b shows that the wake area occurring is almost as large in all T/D. A similar wake area is also shown in figure 3c, the flow velocity profile in wake at a distance of 11D is calculated from the center of the cylinder. The narrow wake indicates that the separation point is more delayed behind and physically indicates that the flow momentum attached to the cylinder is more turbulent. In addition to the area of wake, the wake shapes that occur as a whole symmetry, meaning that nothing lift force occurs.

(a)

(b)

(c)
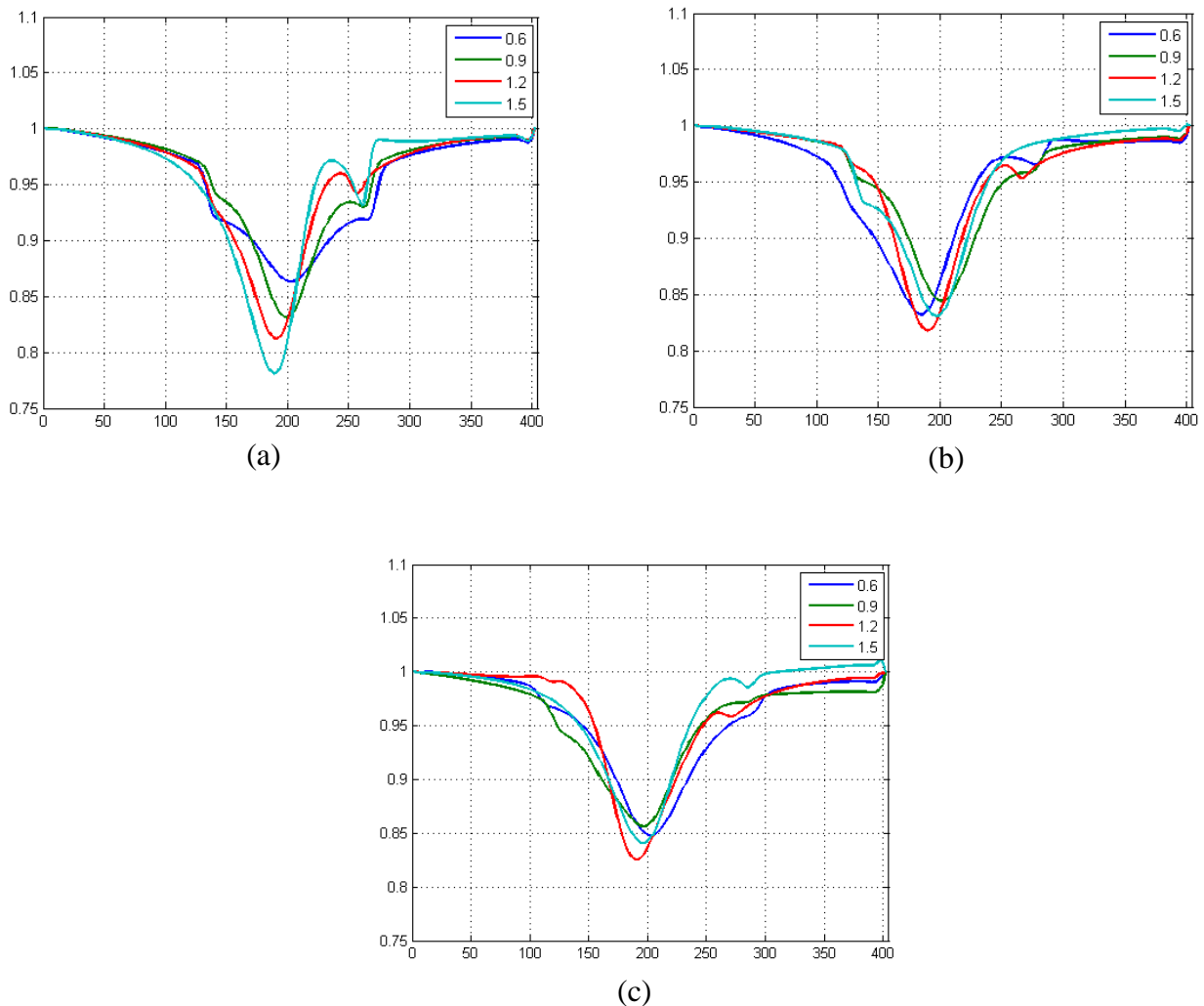
Figure 3: *The velocity profile at wake area : (a) wake at the distance 6D (b) wake at the distance 8.5D and (c) wake at the distance 11D*

3.3 Drag Coefficient

Remind that the aim of this investigation was to determine the effect of two passive controls with variation distances on the drag received by the circular cylinder. So, drag is calculated when the circular cylinder wasn't given by passive control and circular cylinder using single passive control which form is cylinder type I that located in front of circular cylinder. The passive control cylinder type I shape is chosen because it has been proven to minimize the drag received by the cylinder (Igarashi & Shiba, 2006, Imron et al., 2013). Drag of circular cylinder without passive control and single passive control in Reynolds 5000 shown in table 2.

Table 2: *Drag coefficient of cylinder using single passive control*

Circular Cylinder		Reynolds 5000
Without Passive Control		1.5075
Single Passive Control Cylinder Type I	0.6	1.4550
	1.2	1.2730
	1.8	1.2210
	2.4	1.2240
	3.0	1.2160

Based on table 2, single passive control can reduce the drag received circular cylinder. Smallest drag received by circular cylinder happen at $S/D=3.0$ which passive control can reduce the drag 19.33% of drag without passive control. Then, investigation is done in the circular cylinder with two passive controls. The second passive control is placed behind the circular cylinder to be the object of investigation. The result of drag received by circular cylinder with two passive controls is shown in table 3 and table 4.

Table 3: *Drag result of second passive control ellipse shape*

Reynolds 5000		T/D					
		0.6	0.9	1.2	1.5	1.8	2.1
S/D	0.6	1.155	1.172	1.151	1.368	1.461	1.404
	1.2	1.005	1.016	1.004	0.941	1.225	1.229
	1.8	0.967	0.991	0.967	0.906	1.183	1.160
	2.4	0.986	0.983	0.980	0.925	1.193	1.163
	3	0.982	0.991	0.976	0.957	1.193	1.157

Circular cylinder with second passive control ellipse shape receive the smallest drag in $S/D=1.8$ and $T/D=1.5$ when Reynolds 5000. The drag can be reduced up to 39.9% to without passive control, and 25.79% to single passive control cylinder type I.

Table 4: *Drag result of second passive control horizontal cylinder type I shape*

Reynolds 5000		T/D					
		0.6	0.9	1.2	1.5	1.8	2.1
S/D	**0.6**	1.162	1.204	1.164	1.477	1.436	1.420
	1.2	1.009	1.043	1.010	0.946	1.254	1.254
	1.8	0.966	1.017	0.972	0.916	1.204	1.191
	2.4	0.988	1.011	0.985	1.241	1.204	1.192
	3	0.981	1.012	0.983	1.240	1.196	1.182

Circular cylinder with second passive control cylinder type I shape receive the smallest drag in and when Reynolds 5000. The drag can be reduced up to 39.24% to without passive control, and 24.98% to single passive control cylinder type I.

The combination of passive control of cylinder type I and ellipse able to minimize the drag received circular cylinder is good enough. This condition occurs at the first passive control distance that is $S/D = 1.8$ and the second passive control distance is $T/D = 1.5$.

3.4 Mathematical Model of the Drag Coefficient

The simulation result of the drag coefficient with two passive controls was interpolated to obtain the mathematical model of the drag coefficient. Approach to formation of mathematical model is made by bilinear interpolation approach. Bilinear interpolation is the development of linear interpolation of two variables (Press et al., 2013). In this case, the variables used are $(x, y) = (T/D, S/D)$. The interpolation formulation is formed by taking the nine points of drag data that have been obtained from the simulation results. It will be obtained nine polynomial equations and nine unknown coefficient. The polynomial interpolation function can be written as follows :

$$f(x, y) = a_{00} + a_{01}y + a_{02}y^2 + a_{10}x + a_{11}xy + a_{12}xy^2 + a_{20}x^2 + a_{21}x^2y + a_{22}x^2y^2 \quad (4)$$

In the case of circular cylinder with passive control cylinder type I and ellipse, we take data of the drag in table 5. Then $(x, y) = (T/D, S/D)$ will be substituted into $f(x, y)$ to find unknown coefficients.

Table 5: *Nine data result of second passive control ellipse shape*

f(T/D,S/D)		T/D		
		0.6	**1.5**	**2.1**
S/D	**0.6**	1.155	1.368	1.404
	1.8	0.967	0.906	1.160
	2.4	0.982	0.957	1.157

Based on table 5, obtained mathematical model of drag coefficient as follows :

$$E(x, y) = 0.5285 + 0.7314y - 0.1675y^2 + 1.6517x - 2.2506xy + 0.5074xy^2 - 0.5398x^2$$

$$+ 0.8142x^2y - 0.1847x^2y^2 \quad (5)$$

Comparison surface of mathematical model in equation 5 that obtained against data of simulation can be shown in figure 4.
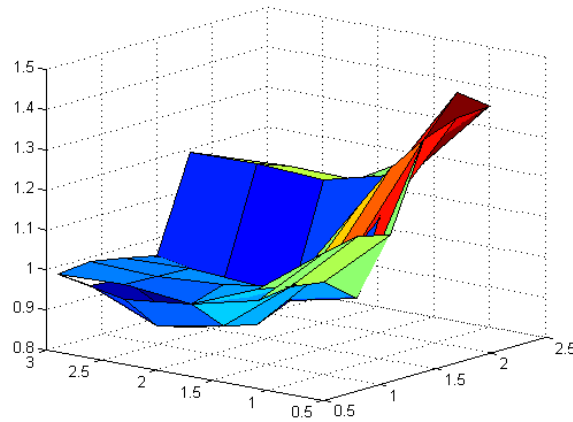
Figure 4: *Comparison surface of mathematical model equation (5) passive control ellipse shape against data of simulation.*

Error from the above mathematical model, calculated using absolute error as follows :

$$e(x, y) = |E(x, y) - f(x, y)| \quad (6)$$

Calculation result from error every point got the biggest error from drag coefficient mathematical model of circular cylinder with passive control of cylinder type I and ellipse that is 0.22668.

Table 6: *Nine data result of second passive control horizontal cylinder type I shape*

f(T/D,S/D)		T/D		
		0.6	**1.5**	**2.1**
S/D	**0.6**	1.162	1.164	1.420
	1.8	0.966	0.916	1.191
	2.4	0.981	1.240	1.182

Then, the case of circular cylinder with passive control cylinder type I and horizontal cylinder type I, we take data of the drag in table 6. The mathematical model of this case was obtained using the same way as was done before.

Drag coefficient Mathematical model of circular cylinder with second passive control horizontal cylinder type I shape is :

$$C(x,y) = 1.2358 + 0.4289y - 2161y^2 + 0.1685x - 1.6392xy + 0.6194xy^2 + 0.0062x^2$$
$$+ 0.2985x^2y - 0.2287x^2y^2 \qquad (7)$$
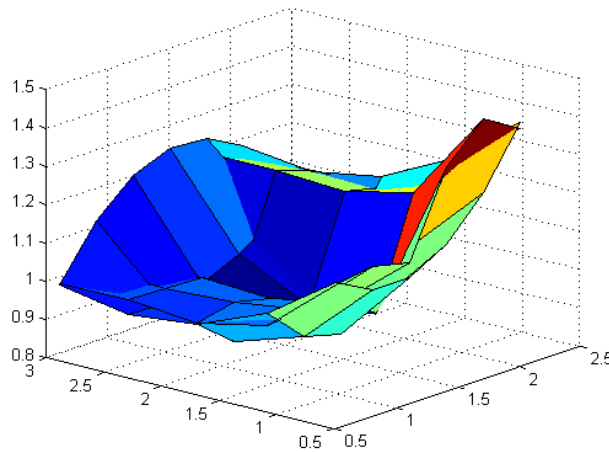
Figure 5: *Comparison surface of mathematical model equation (7) passive control horizontal cylinder type-I shape against data of simulation*

Using error absolute in equation 6 obtained the biggest error every point from drag coefficient mathematical model of circular cylinder with passive control of cylinder type I and horizontal cylinder type I that is 0.283. Comparison surface of mathematical model in equation 7 that obtained against data simulation can be shown in figure 5.

4. Conclusion

The fluid flow research that crosses circular cylinder and two passive controls has been done in Reynolds number 5000. The first passive control is cylinder type I with cutting angle $\theta_f = 53°$ and $\theta_r = 127°$ chosen based on previous research because it can produce good result that drag received circular cylinder can be reduced significantly. The second passive control is researched based on the shape. They are the horizontal position of first passive control and the ellipse. Variations in the distance between the circular cylinder and the passive control affect the drag received by the circular cylinder. The best distance for minimum drag received circular cylinder that is $S/D = 1.8$ and $T/D = 1.5$. This result is also supported by the fluid flow velocity profile taken around the wake region. At that distance the wake region is smaller than the other. Thus the resulting drag is also getting smaller. In this distance, the second passive control is horizontal cylinders type I can reduce drag up to 39.24% of circular cylinders without control. While the second passive control is ellipse can reduce drag up to 39.9% of cylinders without passive control. Thus the best passive control used in Re 5000 is passive control of cylinder type I and ellipse. The mathematical model of drag coefficient that obtained is expected to facilitate in finding the drag coefficient received circular cylinder at the desired distance. Mathematical model of drag coefficient for passive control cylinder type I and ellipse written by:

$$E(x, y) = 0.5285 + 0.7314y - 0.1675y^2 + 1.6517x - 2.2506xy + 0.5074xy^2 - 0.5398x^2$$
$$+ 0.8142x^2y - 0.1847x^2y^2$$

5. Acknowledgements

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