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FLOW AROUND A SQUARE CYLINDER WITH WAVY SPLITTER PLATE PLACED UPSTREAM

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ABSTRACT

This study is focused on the reduction of aerodynamic forces acting on a wavy shape splitter plate placed upstream of a square cylinder. Experiments have been carried out for Reynolds numbers ranging 6200 to 27000 at an attack angle of 0°. *Five different wavy shaped plates and four different straight splitter plates are used. The drag and lift force measurements have been implemented by using a load cell. Drag reduction of wavy shaped Model 3 having an amplitude of 12 mm, a wavelength of 25 mm and a total length of 30 mm is obtained nearly 50% as compared to the single square cylinder. With increasing plate length, there is an inverse relationship between Strouhal number and the drag coefficient. For all straight and wavy plate models, Strouhal number is widely independent from Reynolds number changing from* 6200 to 27000.

INTRODUCTION

Bluff bodies such as circular and square cylinder are encountered in real life structures like building, skyscrapers, bridges and so forth. Flow control around such important buildings is of great importance in terms of decreasing drag coefficient and suppress vortex induced vibration. There are two main classifications for flow control. The first one is active flow control methods such as synthetic jet [Mane et al., 2007], plasma actuators [Akbıyık et al., 2017], and moving surface [Korkischko and Meneghini, 2012]. The second one is passive flow control methods such as splitter plate [Akansu et al., 2004; Sarioglu et al., 2006], control rod [Sarioglu et al., 2005; Akansu et al., 2011; Firat et al., 2015]. Investigation of the effects of the splitter plate on the flow around bluff bodies starting with the study of [Roshko, 1954] still continues by researchers even todays. Many researchers investigated the influence of straight splitter plate placed behind square [Sarioglu et al., 2006; Ali et al. 2011; Sarioglu, 2016], circular [Apelt and West, 1975; Akansu et al., 2004; Akilli et al., 2008; Yucel, Cetiner and Unal, 2010] and rectangular cylinders [Rathakrishnan, 1999]. [Anderson and Szewczyk, 1997] investigated the effect of a wavy shaped splitter plate placed behind a circular cylinder at the attack angle of 0°. They measured velocities by using a hot wire anemometer to

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acquire vortex shedding frequency. They showed that the wavy shape plate had nearly same effect with straight splitter plate. [Bearman and Owen,1998] experimentally investigated to the influence of spanwise waviness of separation lines. Their results indicated that drag reduction is obtained up to 30%. [Darekar and Sherwin,2001)] performed a numerical study to investigate the effectiveness of square cylinder having wave shaped stagnation face at Re = 10-150.

The objective of this study is to investigate the influence of the wavy shaped splitter plate in front of the square cylinder in terms of drag reduction and lift generation for low subcritical Reynolds number range at the attack angle of 0°. The main purpose in here is to reveal the effect of the wavy shaped splitter plate in front of the square cylinder in terms of converting 2-dimensionality into 3-dimensionality in flow structure. Especially, it is contemplated that the flow structure around the cylinder can be controlled by means of the shape and thickness of the wavy-shaped plate.

METHOD

The experiments are carried out in a suction type wind tunnel having test section of 57 cm x 57 cm. Turbulence intensity of the tunnel is smaller than 1%. The square cylinder has side length (D) of 30 mm and a span length of 300 mm. Blockage ratio is equal to 2.77%. Reynolds numbers based on D, are 6200, 8829, 11609, 14062, 16678, 19130, 21746, 24362 and 27000. Figure 1 shows the schematic of experimental setup composing of a wavy shaped splitter plate, a square cylinder, a connection rod, a rotary unite and a load cell in a wind tunnel. End plates are used to provide two dimensionality. The test model consisting of a splitter plate, end plates and a connection rod was centrally placed to the test section. Force measurements were implemented with a six-axis ATI Gamma DAQ F/T load cell which is attached to the rotary unit. Force data were collected as 10000 data at a sampling frequency of 0.5 kHz with the help of NI PCIe-6323 DAQ card. The load cell could measure forces up to ±32 N at the direction of x and y-axis. All experiments have been performed twice in order to provide repeatability of measurements. Vortex shedding frequency acting on the test model is acquired from fast fourier transform (FFT) with the help of a time history of a lift force.

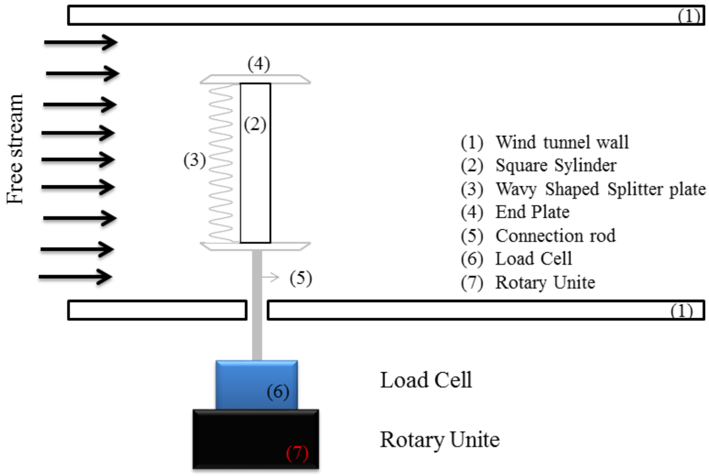

Figure 1*:* Schematic view of the experimental setup.

In this study, four different straight splitter plate and five different wavy shaped models having the same wavelength and amplitude are given in Table 1. Model numbers of M1, M2, M3, M4 and M5 denote the wavy shaped splitter plates having different total length. In addition, M6, M7, M8 and M9 denote the straight splitter plates. The geometry of the wavy shaped splitter plate is defined as Lx = a·sin (2πx/λ), where Lx is the local width of the plate, “a” is the amplitude of the wave, x is the spanwise location and λ is the wavelength of the wavy plate as seen in Fig. 2. All of the plate models are made from Plexiglass® sheet of 3 mm thickness.

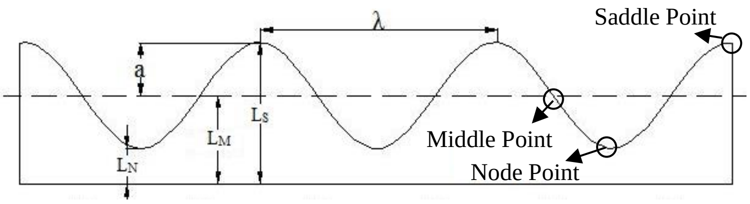

Figure 2: Schematic view of the wavy shaped splitter plate models

Table1: Geometric parameters of wavy shaped splitter plate

Geometric Parameters of Plate (mm)	**Wavy shaped splitter plate**					**Straight splitter plate**		
	M1	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**M8**
Amplitude (a)	12	12	12	12	12	-	-	-
Wavelength (λ)	25	25	25	25	25	-	-	-
Node point length (L_N)	6	12	18	24	30	-	-	-
Average length ($L_{M.}$)	12	18	24	30	36	-	-	-
Total length (L_S)	18	24	30	36	42	12	16	18

RESULT

Figure 3 shows the variation of the mean drag coefficients (C_D) for the Reynolds number range between 6200 and 27000. For wavy shaped splitter plate models, drag coefficient gradually decreases with increasing total length of the plate up to 30 mm (M3). M3 indicates similar variation with M4 (total length of 36 mm) at almost all Reynolds number range. Drag coefficient slightly increases for M5 having a highest total length as compared to M3 and M4. It is seen that maximum drag reduction is obtained as 50% for M3 and M4 when compared the values of the square cylinder alone for the Reynolds number range between 14062 and 27000.

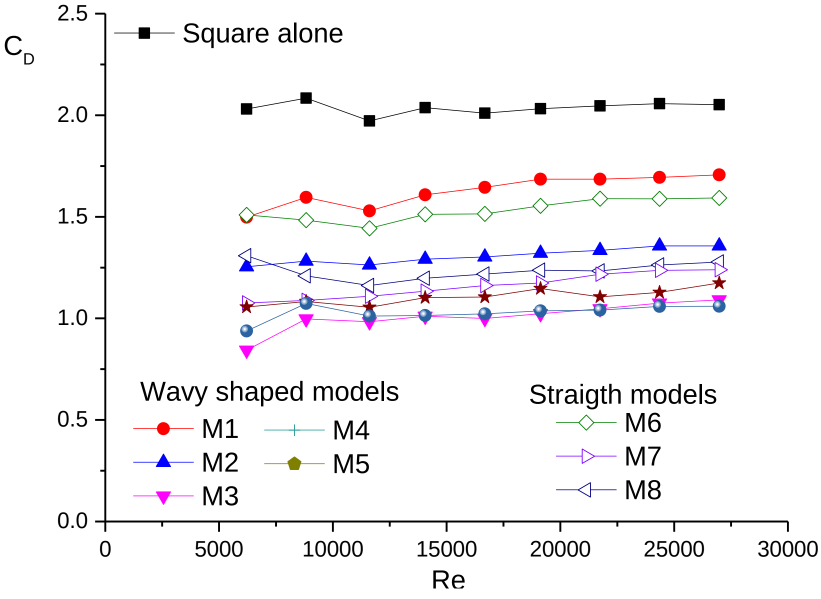

Figure 3: Drag coefficient variation versus Reynolds number.

The variations of the lift coefficient versus Re for the square cylinder with/without 4wavy or straight plates are plotted in Fig. 4. Although the splitter plates placed in front of the square cylinder at the same symmetry axis, the mean lift coefficients are obtained with a different value than zero level for some models. It is difficult to obtain the bilateral symmetry of flow structure around the square cylinder even if the splitter plates were located in the centre plane of flow field of the square cylinder. This asymmetric flow can be associated with the instability of the attached flow on the front face due to a thickness of the plate with a small deflection in the angle of attack. This instability naturally will be more effective for the straight models and it will increase with increasing length of the plate. These negative or positive values around the zero level are related to the direction of the deflection in the attack angle.

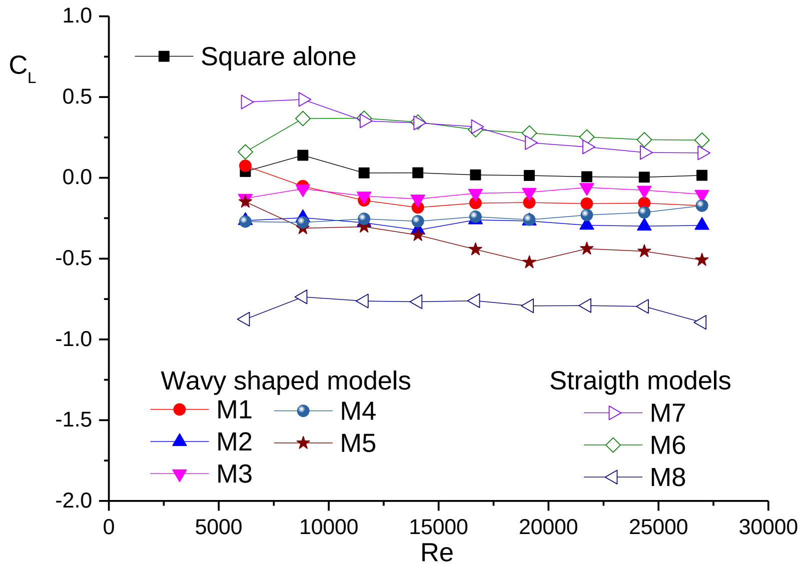

Figure 4: Lift coefficient variation versus Reynolds number.

Time history of the fluctuating lift force data showing in Fig. 5(a) is used in FFT analysis for the case of Re=19130. The vortex shedding frequency obtained from FFT analysis for the bare square cylinder is plotted in Fig. 5(b). Dominant vortex shedding frequency (f_s) is obtained as 50.5. Strouhal number (*St*) can be defined as $St = (f_s\ D) / V$ here, *St* is Strouhal number calculated based on *D*, *D* is the side length of the square cylinder, f_s is vortex shedding frequency and *V* is the velocity of the free stream.

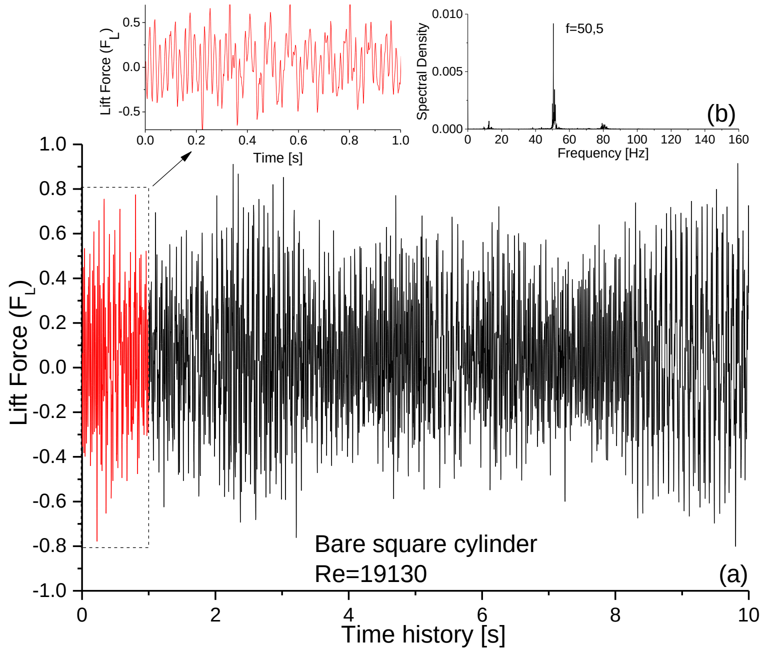

Figure 5: (a) Time history of the fluctuating lift force data and (b) the vortex shedding frequency obtained from FFT analysis for the bare square cylinder at Re = 19130.

In the case of M3 splitter plate, time history of the fluctuating lift force is given in Fig. 6. For alone square cylinder, the oscillations of fluctuating forces are in the range of ±0.6, whereas in the case of M3, the fluctuating forces are suppressed up to ±0.2 range. For bare cylinder, vortex shedding frequency is seen at 50.5 Hz as a narrow peak in spectral density graphic. In the case of using of the wavy plate, multiple peaks and fluctuations are widely obtained in the frequency domain. Especially, the value of dominant peaks increases beyond to 66 Hz. This distribution in frequency domain reveals the effect of the wavy shaped passive control plate as a 3-dimensional flow structure generation device. Multiple peaks show 3-dimensionality and irregularity in the flow structure, the increase in the frequency point out smaller vorticities which cause totally reduction in the drag forces.

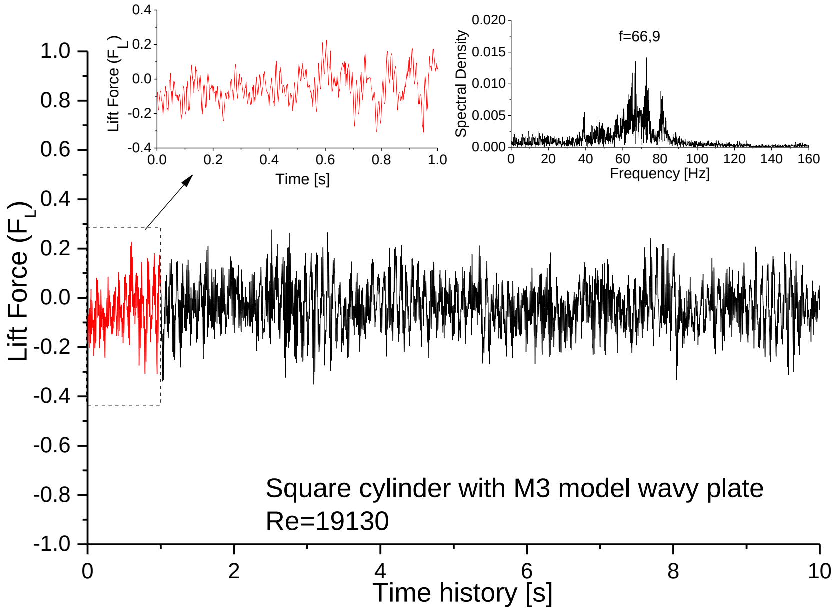

Figure 6: (a) Time history of the fluctuating lift force data and (b) the vortex shedding frequency obtained from FFT analysis for the square cylinder with M3 model wavy plate at Re = 19130.

Comparison of the Strouhal number variation with the available studies in literature is given in Figure 7 for different Reynolds numbers. The Strouhal number of Square cylinder for the present study indicates good agreement for the study of Igarashi (1984), Obasaju (1983) and Sarioglu et al. (2006) at wide Reynolds number. The variation of Strouhal number as a function of Reynolds number for the square cylinder with/without splitter plate model(s) are presented in Figure 8. St of M1 obtained the minimum drag reduction is nearly the same with that of bare square cylinder. There is gradually increase in Strouhal number with the increasing of total length of wavy plates and straight plates. When total length of splitter plate for straight and wavy is increased, drag coefficients are decreased and Strouhal numbers are increased therefore there is an inverse relationship between Strouhal number and the drag coefficient with increasing plate length. This increase in St can be attributed to three dimensional flow structure around square cylinder with wavy plate. For Reynolds number range between 6200 and 27000, Strouhal number is independent from Reynolds number for all models.

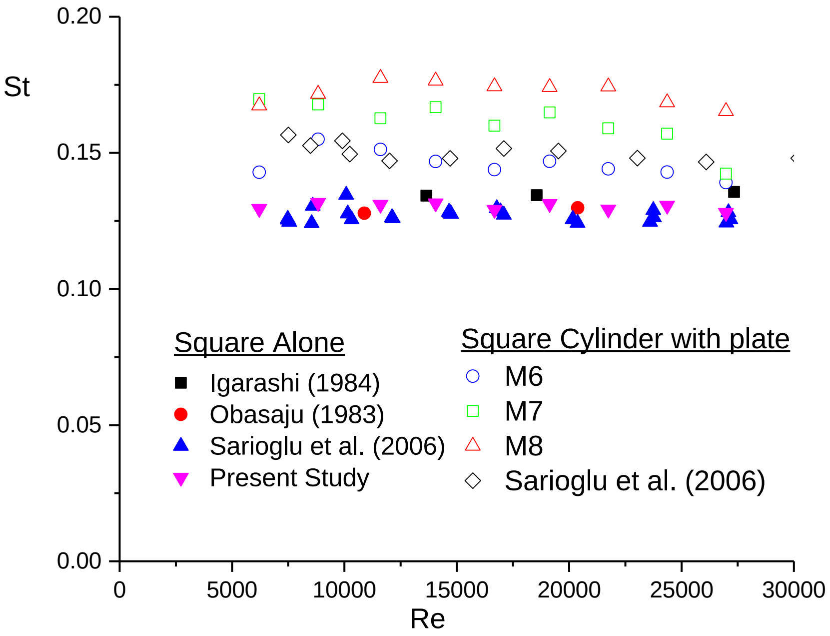

Figure 7: Comparison of the Strouhal number variation for different Reynolds number with the available studies.

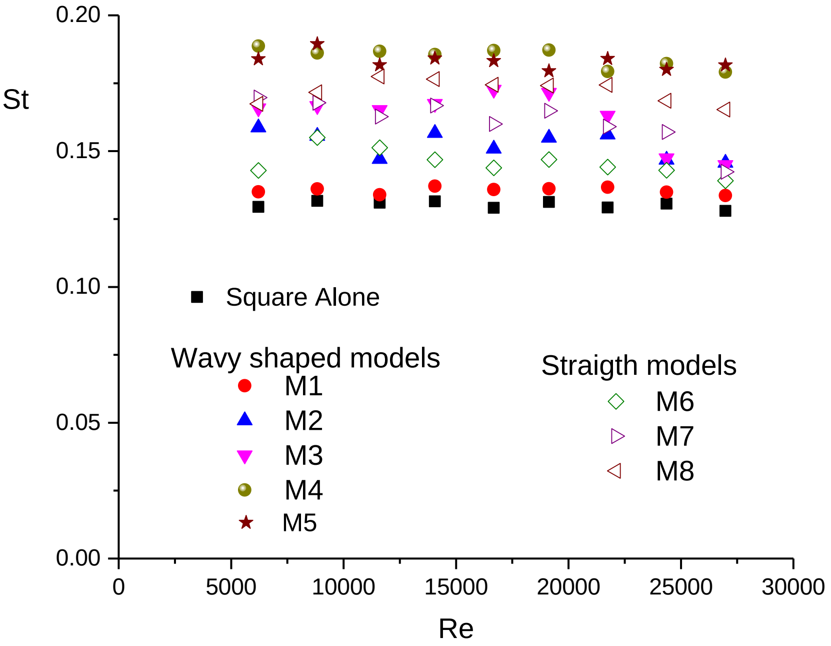

Figure 8: The variation of drag coefficient with Reynolds number for different test models.

CONCLUSION

An experimental study is performed to investigate effects of wavy shape splitter plate placed upstream of a square cylinder. Lift and drag forces acting on the square cylinder are measured so as to obtain Strouhal number, lift ad drag coefficient at wide Reynolds number range changing between 6200 to 27000 for the angles of attack of 0°. Maximum drag reduction is obtained as 50% for M3 and M4 as compared to the square cylinder alone for the Reynolds number range between 14062 and 27000. Fluctuating lift forces are suppressed up to ±0.2 range due to three dimensional effects. Strouhal number is independent from Reynolds number for all models.

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