

Effectiveness of Splitter Plate in Suppressing the Flow-Induced Vibration of a Circular Cylinder

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Abstract. The effectiveness of splitter plate as suppression device in reducing the flow-induced vibration (FIV) of a circular cylinder was conducted experimentally. The parameter used in this experiment is the gap separation between splitter plate and the circular cylinder (G/D). The control element of gap separations are varied from 0.5 to 2.0. The experiments were conducted in the wind tunnel which was free from external wind conditions at Aeronautical and Wind Engineering Laboratory (AEROLAB), UTM Kuala Lumpur. A supporting structure was designed and fabricated with the purpose to allow free vibration induced by wind on the circular cylinder. The results were analysed through the response of amplitude and power spectral density of the circular cylinder with splitter plate and compared with bare circular cylinder. For the gap separations of $G/D = 1.0, 1.5$ and 2.0 , the vibration of the circular cylinder were successfully suppressed. The optimal distance for gap separation was at $G/D = 1.5$ with suppression effectiveness of 82%. For $G/D = 0.5$, on the contrary, the vibration of the circular cylinder was amplified. As conclusion, splitter plate can function to suppress as well as amplify the vibration of cylinder, depending on the gap separation.

1. Introduction

Flow over a bluff body such as circular cylinder has raised a remarkable attention in fluid mechanics as it is usually related in many practical situations such as infrastructures and buildings. Maruai et al.[1] stated that bluff bodies were portrayed by the substantial flow that separated and corresponded with the vortex shedding that occurred and produced oscillation when being immersed in fluid flow. Therefore, controlling the vortex shedding from bluff bodies is very crucial to avoid any catastrophic accident.

FIV can cause disastrous failure to a system or structure when the shedding frequency of the vortices behind the wake flow is “lock-in” with the structural natural frequency. The lock-in phenomenon is occurred due to the synchronization between the shedding frequency of the vortices and the structural natural frequency. The failure that caused by FIV is usually costly and requires a lot of concern and effort in order to mend it. The phenomenon of FIV have been experienced in various fields such as civil engineering (tall buildings, chimneys, bridges) [2], aerospace industry [3], power transmission



(turbine blades, heat exchangers) [4], oil exploration (offshore platforms) [5] and others. Thus, numerous studies have been conducted in order to modify the fluctuating wake flow of the structure and also to suppress the shedding of the vortices.

Basically, in order to alter the wake behind the structure and reduce the FIV, there are two main methods that can be used which are active and passive control techniques. However, passive control techniques have their advantages where the techniques do not require additional power inputs. As stated by Liu et al. [6], the passive control techniques include modifying the near wake flow of the structure by implementing additional devices in the wake flow such as splitter plates and fairings or by altering the obstacle geometry using strakes.

The studies of passive techniques by using splitter plates still have to be done more especially on its suppression performance. To investigate the reduction of the flow-induced vibration (FIV) in a circular cylinder, splitter plates of various gap separation between splitter plate and circular cylinder (G/D) are tested in the present study to figure out the optimum distance for this suppression device.

2. Methodology

The experiments are conducted at the Aeronautical and Wind Engineering Laboratory (AEROLAB) in UTM Kuala Lumpur, Malaysia. A steel supporting structure is fabricated with the measurements of $0.29m \times 0.29m \times 0.29m$ in length, width and height, respectively. The circular cylinder used in the experiment is made by polyvinyl chloride (PVC). The selection of the PVC material is due to the light weight. The specifications of the PVC cylinder are shown in table 1.

Table 1. Specifications of the circular cylinder.

Specification	Value
length of the cylinder (m)	0.175
Outer diameter (m)	0.022
Wall thickness (m)	0.002
Mass (g)	33

At each end of the circular cylinder, two holes are made in order to attach the coiled spring on the supporting structure. The stiffness of the spring used is in low stiffness which is $29N$. The speeds tested are from $1m/s$ to $5m/s$ with interval of $0.5m/s$. The suppression effectiveness of splitter plate is investigated based on the gap separations between splitter plate and circular cylinder (G/D). The schematic sketch of circular cylinder with splitter plate can be seen in figure 1 where L is the length of the plate.

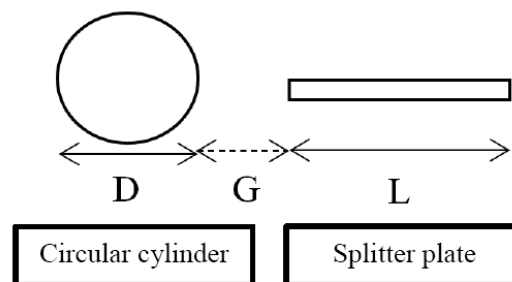


Figure 1. Schematic sketch of circular cylinder with splitter plate.

The values of the parameter that are selected to be used when conducting the experiment are based on table 2.

Table 2. Values of parameter used in the experimental work.

Parameters	Ratio (G/D)
Gap separations between splitter plate and circular cylinder (G/D)	0.5, 1.0, 1.5, 2.0

A video recorder is used to record the motion of the cylinder. The frame per second (FPS) of the recorder is 30, which is adequate to capture the motion of the cylinder. Then, Tracker video analysis and modelling tool software is used to extract the vibration data of the circular cylinder. The video of the circular cylinder that experiencing flow-induced vibration (FIV) needs to be uploaded into the software to be analysed. Before analysing the video, calibration need to be done by setting the coordinate axes and scaling the video using calibration stick. Then, the reference point which can be determined manually is set. After that, the video can be analysed and the amplitude can be obtained. To get the frequency response, ANSYS software is used by converting the amplitude gained from the Tracker software using Fast-Fourier Transform (FFT). FFT is developed from Discrete Fourier Transform (DFT) with the definition:

$$A(r) = \sum_{k=0}^{N-1} X(s) e^{-i2\pi/N^r s} \quad , r = 0, 1, 2, \dots, N - 1 \quad (1)$$

where $X(s)$ is the periodic wake and s is the number of samples collected from the original signals.

3. Results and discussions

3.1. Verification of the data

Verification of the experiment is needed before start conducting the experiment. The natural frequency is important as the value is needed for the calculation of reduced velocity, U_R , where $U_R = U / f_n D$. U is the flow velocity, f_n is the natural frequency and D is the diameter of the cylinder. The natural frequency can be obtained from the free decay test that is performed by pulling down the cylinder and let it freely vibrates until stagnant position. The time series data from the free decay test is converted into frequency domain using ANSYS software and subsequently, the value of the natural frequency can be obtained. To ensure the validity of the experimental natural frequency, the result is compared with the theoretical value which can be calculated by using the formula:

$$f_n = \frac{\sqrt{k/m}}{2\pi} \quad (2)$$

Where f_n is the natural frequency, k is the stiffness of the system and m represents the mass of the circular cylinder. From table 3, the experimental natural frequency is 8.64 Hz while from the theoretical calculation, the value is 9.44 Hz. The percentage difference between both theoretical and experimental value is 8.47 %. Cecconi et al. [7] stated that the percentage error that usually used as reference has precision of $\pm 20\%$ or less. Since the percentage difference of the present study is small, it can be concluded that the experimental rig is reliable and can proceed to the experiment. In the calculation of reduced velocity of the present study, the experimental value of natural frequency, f_n is used instead of the calculated value.

Table 3. Percentage difference on the natural frequency between theoretical and experimental values.

Experimental	Theoretical	Percentage difference (%)
8.64 Hz	9.44 Hz	8.47

3.2. Effect of splitter plate as suppression device

3.2.1. Amplitude response. The ratio form of amplitude can be obtained by dividing the root-mean-square of amplitude with the diameter of the circular cylinder, A/D . Based on figure 2, the maximum amplitude response for a bare cylinder is found to be around 0.16. Lock-in region is started at $U_R \approx 4$ and ended at $U_R \approx 10$. The value of amplitude response at $U_R > 10$ is small as lock-in does not occur. After applying the splitter plate, the amplitude of the cylinder is either becomes larger or smaller based on the gap separation (G/D). In the present study, $G/D = 0.5$ results the highest amplitude compared to bare circular cylinder and circular cylinder with other gap separation. It is due to the occurrence of

violent vibration as the frequency of vortex shedding does not approach the natural frequency of the splitter plate [8]. However, at $G/D = 1.0, 1.5$ and 2.0 , the vibration of the circular cylinder is suppressed as the amplitude ratios are lower than the bare circular cylinder. For $G/D = 2.0$, the amplitude response seems to be larger compare to $G/D = 1.0$ and 1.5 as the splitter plate is already too far from the circular cylinder. Hence, the effectiveness of the splitter plate to disrupt the vortex shedding is lesser. The amplitude response of circular cylinder for all gap separation and bare cylinder starting from $U_R > 13$ are in small range as there are no occurrence of FIV.

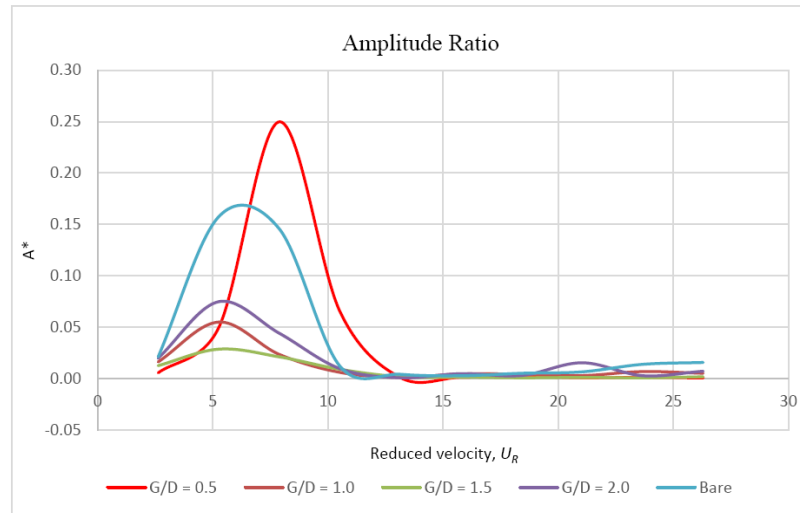


Figure 2. Amplitude ratio of bare cylinder and cylinder fitted with splitter plate of various gap separation.

In order to prove the condition of the lock-in phenomenon, power spectral density for $G/D = 0.5$ and $G/D = 1.5$ at wind speed (V) of 1.5 m/s are shown as in figure 3 and figure 4, respectively. It can be seen that the values of power spectral density for $G/D = 0.5$ are bigger compare to $G/D = 1.5$ because the lock-in phenomenon is occurred in $G/D = 0.5$. Moreover, multiple frequency peaks with lower power spectral density are found for $G/D = 1.5$, while only one significant peak with large power spectral density is found in $G/D = 0.5$.

3.2.2. Suppression efficiency. The effectiveness of the splitter plate have to be determined to justify the performance of splitter plate based on gap separation. The effectiveness of the splitter plate based on the maximum amplitude can be determined by using the expression as follows:

$$Efficiency\ ratio = \frac{(A/D)_{max-bare} - (A/D)_{max-splitter\ plate}}{(A/D)_{max-bare}} \times 100\% \quad (3)$$

Based on table 4 which shows the suppression effectiveness of gap separation, it can be seen the efficiency ratio is the highest at $G/D = 1.5$ with the value of 81.77% . However, for $G/D = 0.5$, the efficiency ratio shows a negative value as instead of suppressing the amplitude, the vibration of the cylinder is amplified. For $G/D = 1.0$ and 2.0 , both of the gap separations are able to suppress the vibration of the circular cylinder with moderate effectiveness. For $G/D = 2.0$, the effectiveness ratio is slightly lower as the splitter plate is too far from the cylinder, hence less disruption on the vortex shedding is experienced by the cylinder.

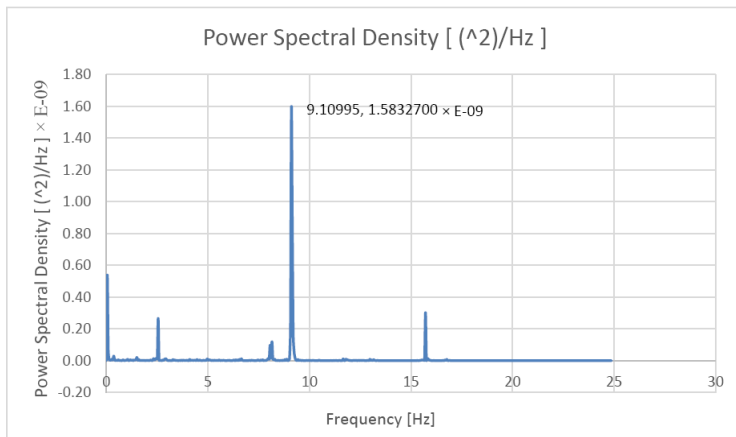


Figure 3. Power spectral density for $G/D = 0.5$ at $V = 1.5\text{m/s}$.

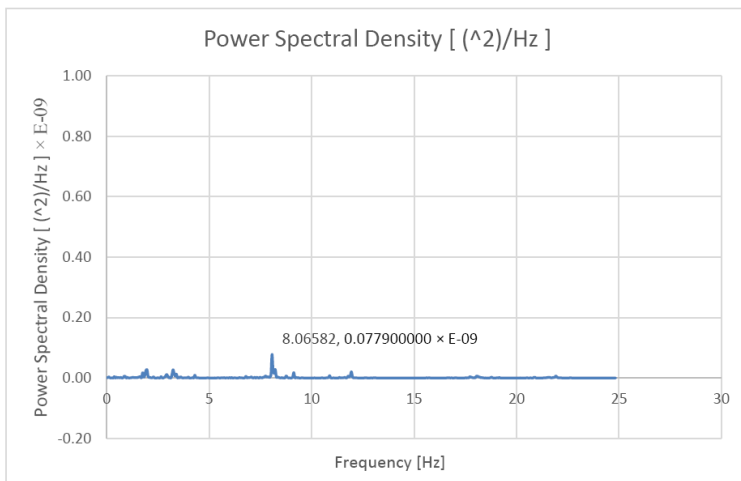


Figure 4. Power spectral density graph for $G/D = 1.5$ at $V = 1.5\text{m/s}$.

Table 4. Suppression effectiveness based on gap separation between splitter plate and circular cylinder (G/D).

Gap separation between splitter plate and circular cylinder (G/D)	Effectiveness ratio (%)
0.5	-58.23
1.0	65.13
1.5	81.77
2.0	52.59

In conclusion, it is effective to use splitter plate to reduce the FIV of a circular cylinder. However, limitation is found on G/D where the amplitude can be suppressed but also can be amplified. Hence, proper gap selection is required in order to avoid excessive vibration. For this experiment, the most successive gap separation is at $G/D = 1.5$. Luk et al. [8] conducted an experiment on the reduction of FIV of circular cylinder using air foil as the suppression device. The authors reported that the frequency and strength of the cylinder’s vortices dropped when the air foil was located at the distance of $1.5D$ behind the cylinder. Although the suppression devices involved are dissimilar (airfoil and splitter plate), it is interesting to find out that the outcomes by Luk et al. [8] are similar with the results obtained in this experiment which the optimum gap separation between the circular cylinder and the suppression device is at $G/D = 1.5$.

4. Conclusions

The FIV phenomenon is occurring in many areas especially in engineering applications. The damages that caused by FIV are very costly. In order to avoid disastrous incident, suppression devices are highly required. Throughout this research, the suppression effect is investigated by using various separation distance between the splitter plate and the circular cylinder, G/D , which are varied from 0.5 to 2.0. The experiments are conducted in a wind tunnel which is free from external wind condition. A supporting structure is designed and fabricated to suspend the circular cylinder so that it can be excited freely depending on the wind speed. Tracker and ANSYS software are used to obtain the data and results for the amplitude and frequency responses. For the gap separations of $G/D = 1.0, 1.5$ and 2.0 , the vibration of the circular cylinder are successfully suppressed. The optimum gap separation to suppress the vibration is at $G/D = 1.5$, where the reduction percentage is 81.77 %. However, for $G/D = 0.5$, the vibration of the circular cylinder is amplified as negative reduction percentage is obtained. There are limitations of the gap separation as the vibration can either be suppressed or amplified.

5. References

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