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EXPERIMENTAL ANALYSIS ON VORTEX-INDUCED VIBRATION OF A RIGID CYLINDER WITH DIFFERENT SPRING STIFFNESS

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ABSTRACT

This project presents an experimental work on vortex-induced vibration (VIV) of a short rigid cylinder to obtain its dynamic responses in cross-flow directions with different spring stiffness. A supporting structure was designed and fabricated to conduct the experiment. This paper aims to investigate the effects of spring stiffness on the characteristics of VIV. The spring stiffness in the experiment were identified using Hooke's Law. This self-designed experiments were conducted using Wind Blower at Aeronautical and Wind Engineering Laboratory (AEROLAB), UTM Kuala Lumpur. By using the accelerometer, the raw amplitude readings were recorded and processed using LMS TestXpress 12 software. The data was recorded in the range of 1 m/s to 8 m/s of wind speed, with interval of 1 m/s. Analysis on the data in terms of amplitude and frequency responses was conducted to identify the effect of spring stiffness on the characteristics of VIV. From the results obtained, the amplitude increases as the frequency close to the natural frequency which is frequency ratio =1. The higher the spring stiffness, the higher the amplitude reduction.

Keywords : *vortex-induced vibration, spring stiffness, rigid cylinder*

1.0 INTRODUCTION

Vortex-induced vibration is one of the main problem faced by the structures in the industry (Hansen, 2007). Structures such as oil pipelines, high chimneys, slender buildings as well as bridges are highly threaten by this vibration. The condition will become worse if synchronization, or known as lock-in phenomenon occurs. Lock- in is said to be occurred when the vortex shedding frequency becomes close to the natural frequency of the structure. Large and damaging vibrations can be resulted, and hence bringing destructive catastrophic. The vibration may cause the structural failure and also accelerate the structural fatigue failure. From the above factors, industry have to bear a higher cost of investment of the structures and expenses for maintenance and pipeline replacement.

All these problems give an attraction towards researchers to investigate the lock-in phenomenon and the effect of fluid and structure towards the VIV. As the cylinder is widely used in structural industries, many researchers used cylinder as the main object of their investigations (Sarpkaya (1979), Sarpkaya (2004), Griffin and Ramberg (1982), Bearman (1984), Bearman (2011), Parkinson (1989), Blevins (1990), Naudascher and Rockwell (1994), Sumer and Fredsøe (1997), Govardhan and Williamson (2000), Govardhan and Williamson (2008), and Blevins and Coughran (2009). Based on the previous studies, only limited sources are found that focus on the effect of spring stiffness towards the VIV of a cylinder.

Zahari et al. (2015), is one of the studies that investigated the effects of spring stiffness on the characteristic of VIV. In the study, a fix spring with stiffness of 100 N/m is used, but the true spring stiffness is obtained based on different diameter of tested cylinder. The study figures out that spring stiffness is the significant parameter to investigate the relationship between amplitude of cylinder and frequency ratio. Therefore, it can be concluded that the spring stiffness affects the natural frequency of a oscillation body and it can contribute to the occurrence of lock in phenomenon. *Amandol`ese* et al. (2010), on the other hand, used the spring with the value of stiffness, k= 597.6 ±35 N/m. The value of spring stiffness is constant in order to present the result on vortex-induced transverse oscillation of a flexibly mounted rigid square cylinder in a uniform airflow. Kang et al. (2003) proposed an axial-flow-induced vibration model to evaluate the sensitivity to spring stiffness on the FIV of the bluff bodies.

To the best of our knowledge, the study on the spring stiffness of the cylinder is very limited. Therefore, the present paper aims to investigate the effect of spring stiffness of a cylinder towards VIV.

2.0 METHODOLOGY

A supporting structure is designed with the dimensions as shown in Figure 2.1. The material and measurements of the cylinder are shown in Table 2.1. At each corner of the cylinder, a hole is made to place the coiled spring. The spring is placed in order to suspend the cylinder in the support structure.

Table 2.1 Properties of the test cylinder

Items	Properties
Total length (m)	0.20
Outside diameter (m)	0.022
Wall thickness (m)	0.002

2.1 Spring Selection

Spring selection is one of the main concern in this experiment because the vibration of the cylinder will be influenced by the stiffness of the spring. Three different spring stiffness is used to achieve the objective. The stiffness of springs can be obtained by conducting an experiment that implement the principle of elongation of spring using the formula F=kx , where F is the force applied to the spring in Newtons (N); k is the spring constant measured in kilo Newtons per meter (kN/m) and x is the distance of the spring that is stretched from its equilibrium position in meters (m). Each spring undergoes three times of trials to get the average value of spring stiffness. Table 2.2 shows specification of spring used in the experiment.

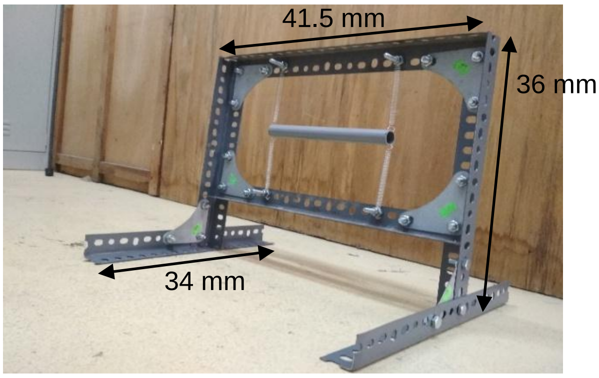

Figure 2.1 Measurement of support structure

Table 2.2 spring selection

Type of spring	Stiffness value (kN/m)
1	0.9491
2	0.7596
3	0.3374

Before conducting the real experiment, the free decay test needs to be conducted to determine whether the experimental approach is appropriate or not. Then, Hookes's law is conducted to find the spring stiffness. After that, the real experiment can be carried out. The accelerometer is attached at the middle of the outer surface of the cylinder using superglue. Siemens LMS Scadas XS is connected to the accelerometer to record the raw data. Then, the supporting structure is placed in front of the wind blower, as shown in Figure 2.2. This experiments are run under 8 different wind speed. The minimum speed is 1m/s while 8m/s is the maximum speed. The wind speed is increased slowly in order to obtain the dynamic responses of each speed conditions. The data is start recorded when the vibration of cylinder is uniform.


Figure 2.2 Experimental setup

3.0 RESULTS AND DISCUSSION

Based on Figure 3.1, the obtained raw amplitude data from LMS software shown that the rigid cylinder has undergone a clear decay test with easy interpretation.

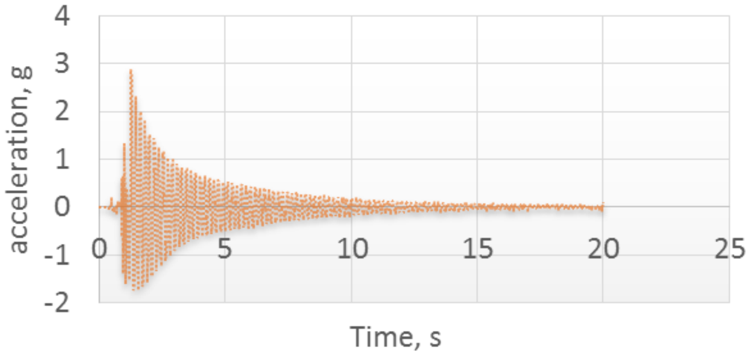

Figure 3.1 Free decay test

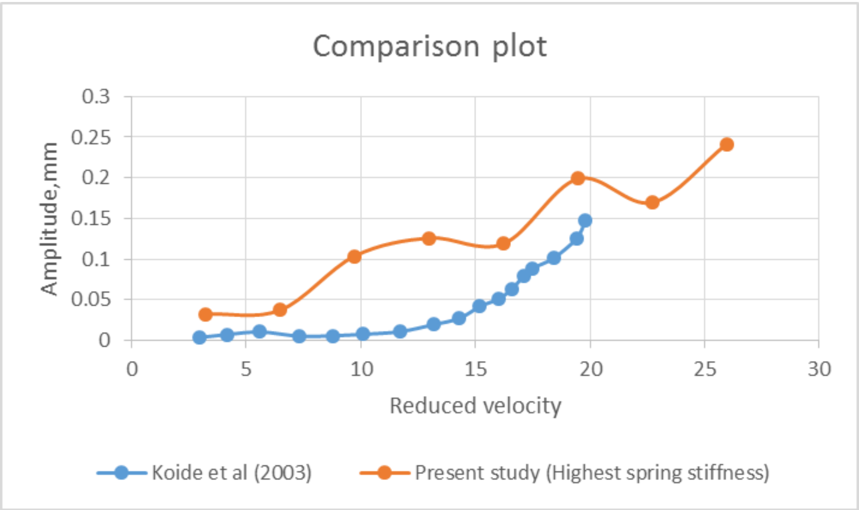

Figure 3.2 Comparison of graph pattern

Koide et al (2003) has investigated the effect of slenderness on cross flow oscillation of a cylinder supported by cantilever in uniform flow. In the study, he stated that the large oscillation of amplitude is called galloping. As the velocity increases, galloping and fluctuating will become other factors that affect the amplitude value. Based on Figure 3.2, it can be seen the amplitude value for both of the present and previous study (Koide et al,2003) are increasing. But the amplitude of the present study is slightly higher than previous one. Based on the result, it can be used to validate the experiment data of the present study.

3.1 Analysis on Spring Stiffness

Figure 3.3 shows the amplitude ratio of different spring stiffness. As the main objective of this research is to investigate the effect of spring stiffness toward the behavior of VIV, three different spring stiffness is used in this experiment. From the graph, it can be concluded that the lower the spring stiffness, the higher the amplitude value. For the middle and lowest stiffness, lock-in region is found at the low reduced velocity (Vr = 3~8). The reduced velocity is defined as Vr=U/f_nD, where U is the flow velocity, f_n is the natural frequency of the cylinder, and D is the diameter of the cylinder. On the other hand, no high amplitude is found for the highest spring stiffness at low reduced velocity (Vr = 3). Therefore, it suggest that spring with highest stiffness is able to suppress the lock-in region in low reduced velocity.

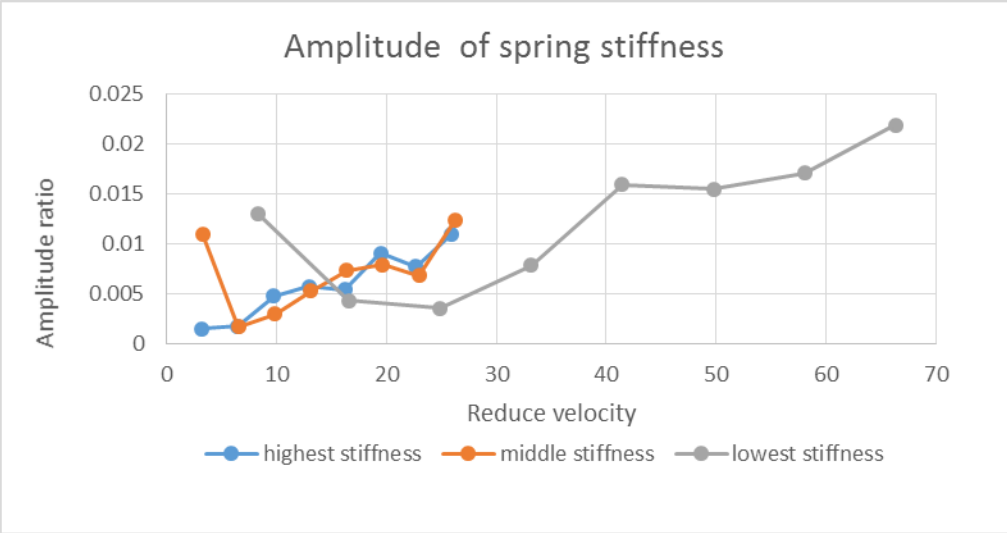

Figure 3.3 Amplitude ratio of spring stiffness

Figure 3.4 shows the frequency ratio of different spring stiffness. As can be seen in the graph, the frequency ratio is found to be 1 for both highest and middle stiffness, indicating that this cylinder is undergoing lock-in condition. But for the lowest stiffness, the frequency ratio is about 0.8. Supposedly, the frequency ratio of lowest stiffness should be at 1, as it shows the highest amplitude value in figure 3.3. Therefore, it is expected that some experimental errors may occur that cause this issue. It is suspected that the accelerometer is improperly placed. Hence, the result is slightly biased.

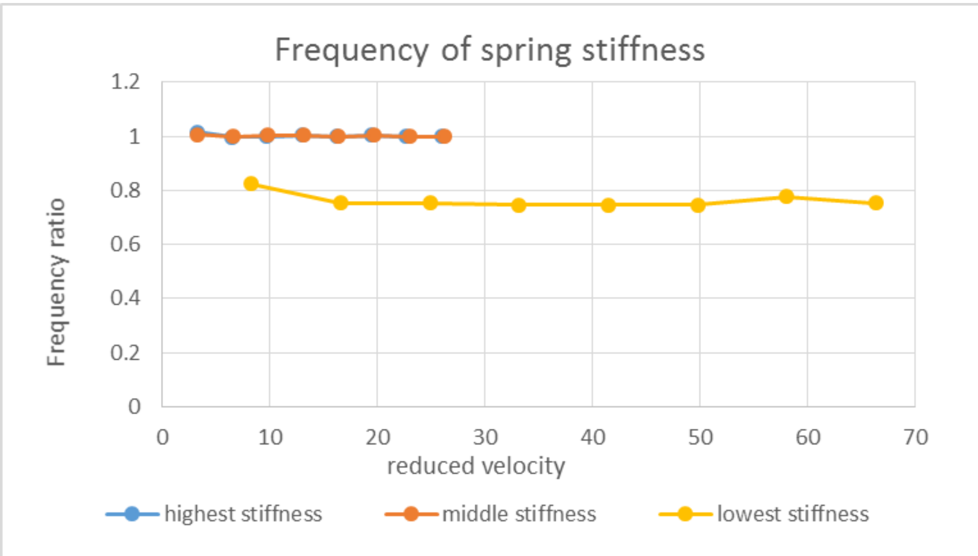

Figure 3.4 Frequency ratio of spring stiffness

4.0 CONCLUSION

In this research, experimental analysis has been performed on a rigid cylinder to analyze vortex-induced vibration and investigate the effect of spring stiffness towards the VIV of rigid cylinder. To make sure the experimental rig is acceptable for the experiment, free decay test has been conducted and validation has been done by comparing the data of the present study with existing study. Then, the real experiment has been conducted at AEROLAB UTM Kuala Lumpur. The raw amplitude readings from the accelerometer were processed analyzed using LMS TestXpress 12 software. The objective of this research have been successfully attained. From the experiment, the vortex-induced vibration effect is successfully simulated on the short rigid cylinder. The amplitude ratio increases as the frequency close to the natural frequency which is frequency ratio =1. From the spring stiffness experiment, the result obtained can be concluded as the higher the spring stiffness, the higher the amplitude reduction. The lock-in region is found at the low reduced velocity range, where the amplitude value is slightly higher. For the highest spring stiffness, these parameters are able to supress the lock-in condition where the amplitude ratio are reduced to a lower values compare to the others.

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