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Flow-Induced Vibration Of A D-Section Subjected To Various Flow Velocities

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Abstract **-** The main purpose of this paper is to examine some practical aspects of a D- section that are related with flow induced vibration. In this work, the first considerable thing that will be covered is the effect of various flow velocities on geometrical shapes and specifically on the D- Section. Therefore, the geometrical properties of shape and its dimensions are very useful to find the value of susceptibility of material to withstand external stress. On the other hand, Young's modulus could have a big effect on the body excitation, the actual geometrical properties of body, which are consisted of one degree of freedom are m= 0.7438032 Kg, K= 1144.8641 N/m, the natural frequency 4.219 rad/Sec, and ζ = 0.00183.The model was developed for one degree of freedom aero dynamic galloping. This model is useful for analysing of elastic D- structure, which was made from polystyrene (C8H8) n and the steel, exposed to various flow velocities where the D- section was put in various attack angles (0 , 45, 90, 135, 180, and then 0)^0 in front of the wind tunnel. Whereas the derivation of the equation of motion of the D- section is the other worthwhile thing because it might be used to simulate the system in the future. The experimental results of the D- section and discussions will be done on some response curves which will be simulated in different ways.

Keywords**:** altering of flow velocities.

Nomenclature

- ρ The volumetric mass intensity
- I The determination geometric bending.
- r Section radius
- m Mass of section
- v The section volume
- h The thickness of steel which is used as a damper.
- C Section damping
- b The width of steel which is used as a damper.
- E Young's modulus
- w Natural frequency
- L The D- section length
- k The stiffness force
- ζ Damping ratio
- D Effective area of the length cross D-section.

1. Introduction

Flow induced vibration (FIV) might draw attention people who care in engineering disciplines. Even though the flow velocity runs out in a uniform direction, the D- Section, which was prepared in this experiment and subjected to various flow velocities and was sat up in various attack angles in front of fan tunnel, is non-symmetric. Many of the previous papers regarding the flow induced vibration. The tunnel of wind was used to experiment flow induced vibration of an elastic circular cylinder by Brika and Laneville (1999). The system which is consisted of one degree of freedom is circular, but the system is fixed with a ridge which is added on the surface of the body. The ridge is used to transfer small vibration amplitude that is called a galloping, as suggested by A.H.P. van der Burgh, Hartono (2004). The one degree of freedom systems are variety of cross section area, so all issues regarding a galloping should be discussed. One of studies has been finished regarding damping parameters of one degree of freedom.

The damping parameters, which is represented as $C^* = \frac{2cw}{p\,U^2}$, are very important in practical aspect for VIV response prediction of elastic structure, investigated by J. Kim Vandiver (2012). In this work, the cylinder is mounted by the spring as the canonical issue that could be used to create comparison between the suggested alternatives $b^*$and $c^*$with the performance of variables of mass damping, studied by Govardhan and Williamson (2006), Khalak and Williamson (1999) and Klamo et al. (2005).

2. The Geometrical Properties and Material Properties

The dimensions and material properties are one of the most important characteristics which are used to simulate the model, so the dimensions and material properties should have been found before starting with an experiment and a simulation for the model.

In this paper, the model is the D-Section which is consisted of polystyrene (C8H8)n as a mass with a steel as the viscous damping coefficient c and spring stiffness k, so the calculations of mass and stiffness for the D-Section should be finished by using the geometrical properties to these materials and the material properties of the body. Hence, and after searching about material characteristics for this model, it is found that the D-Section materials components are a steel and polystyrene (C8H8)n. the main material properties of the model, which were used to solve one issue or more than one in this paper, are Young's modulus E and the densityρ.

Table 1: shown the Geometrical Properties for polystyrene (C8H8)n as a mass and a steel as the viscous damping coefficient c and spring stiffness k.

Geometrical Properties	The mass	The spring
Length	L=28.2 cm	L= 20cm
Diameter, or width	D = 8 cm	b=38.45mm
thickness	-	h=1.06 mm
Material Properties	The mass (polystyrene (C8H8)n)	spring (steel)
Density	ρ = 1.05 g/c m^3	P =7850 Kg/m^3
Modulus of Elasticity	E=3.5 GPa	E= 200 x 10^9 N/m^2

Young's modulus E, also defined as the elastic modulus or the modulus of tensile, is a scale of the stiffness of the elastic of material and is a formula used to characterize substances suggested by Eric Finot et al. (2008). It equals 200 x 109 N/m2, the volumetric mass intensity, or it could be the density of a substance for its mass divided by volume. It equals 7.8 g/cm3, whereas it equals 7850 Kg/m3 for the same material. The ρ is the most common formula used to describe density, density is written as mass per unit volume.

$$\rho = \frac{\mathrm{m}}{\mathrm{V}} \tag{1}$$

2. 1. The Mass Calculations

Form above function, the mass is defined as density multiply by volume:

$$m = v\,\rho \tag{2}$$

A D- Section would have the same shape with a semi- circle. Therefore, the area of a semi-circle will be given:

Area of a semi-circle = $\frac{1}{2}\pi r^2$ = the volume of D- Section = Area of a semi-circle x height (3)

The volume of a D- Section = $\frac{1}{2}\pi r^2$ L (4)

2. 1. 1. The Stiffness Calculations

The Stiffness is defined as material susceptibility to withstand external stress, it depends on material characteristics like a young's modulus, or elastic modulus, a bending moment geometric, and a cross section area. The young's modulus is defined as the ratio of the stress along an axis to the strain. These characteristics would be different from substance to substance. In the work, the D-Section is made from steel, so the steel has young's modulus equaled 200 x 10^9 N/m^2. Whereas the bending moment geometric of steel can be found by measuring model dimensions as presented by S K Mondal, (2013), William T. Thomson et al. (1998).

$$I = \frac{bh^3}{12} \quad (5)$$

$$K = \frac{12\,E\,I}{L^3} \quad (6)$$

2. 2. The Natural Frequency and the Damping Ratio

Natural circular frequency or natural frequency is one of the most important factors which depends on design a system because the natural frequency is the main issue to the occurrence damages in buildings or any facilities or bridges, so the natural frequency should be decreased to prevent a damage. The best way used to decrease a natural frequency is by increasing a mass for the system or decreasing a stiffness, in result of, natural circular frequency or natural frequency can be represented that it is the ratio of stiffness divided by the mass as shown by William T. Thomson et al. (1998).

$$w^2 = \frac{k}{m} \quad (7)$$

The natural frequency can be found by simulating a system as the figure shown 1. From the successive amplitudes of this oscillations, the natural frequency can be defined.

$$f = \frac{1}{T} \quad (8)$$

$$w = 2\pi f \quad (9)$$

After getting a natural frequency for a system, the damping ratio should be easy to find. The damping ratio is dimensionless because it is defined as below and without units as investigated by J. Kim Vandiver (2012).

$$\zeta = \frac{C_s}{2mw} \quad (10)$$

3. Experimental Results of the D- Section and Discussion

The design of a building or industrial tools for big cross- section areas need the expectation of the flow induced vibration an elastic - structure. Such expectations are the goal of programs like SHEAR7 Van diver et al., (2011) that has been used in industry since 1990s.

In this work, the D- section was designed with a big cross section area, and it was subjected to various flow velocities to known cross-flow vibration in describe flow velocity and frequency. Hence begun the need to find a natural frequency to the body oscillation, the process, which was used to find a natural frequency, was completed by plotting a pluck test for amplitude vs. Time as shown in the figure 1.

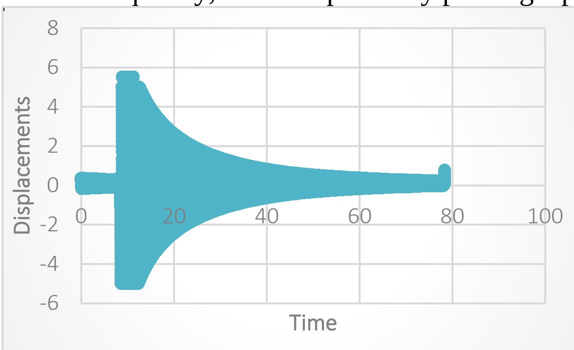

Fig. 1. Shown a pluck test for amplitude vs. Time.

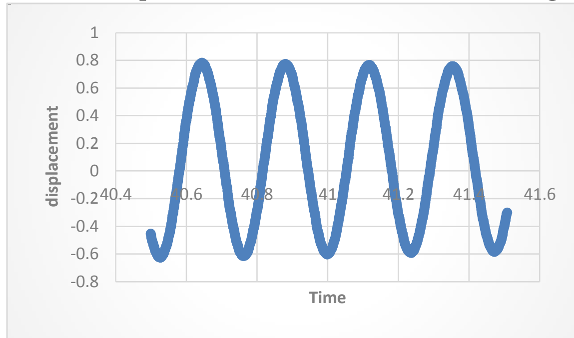

Fig. 2: shown a pluck test for the steady state amplitude at certain time, the periodic response figure is used to find a natural frequency from two successive amplitudes.

From (figure 1), it can be taken a part of the steady state amplitude (figure 2) to find a natural frequency as shown in this calculations.

T_1 = 40.887 Sec, T_2 = 41.124 Sec.
T= $T_2 - T_1$ T= 0.237 Sec.
X_1= 0.762879 mm X_2= 0.754131 mm

Where T represents a time, X represents an amplitude. For successive amplitudes m = 1

$$\ln\left[\frac{X1}{X2}\right] = \frac{2\pi\zeta m}{\sqrt{1-\zeta^2}}$$

$\ln\left[\frac{X1}{X2}\right]$ = Factor reduction amplitude = 0.011533

$0.011533 = \frac{2\pi\zeta}{\sqrt{1-\zeta^2}}$ Square both sides, $0.000133 = \frac{39.4384\,\delta^2}{1-\delta^2}$

$296489.286\,\delta^2 = 1-\zeta^2$, ζ^2= 0.00000337, ζ = 0.00183

$f = \frac{1}{T}$ $f = \frac{1}{0.237} = 4.219\text{Hz}$

$w = 2\pi f$ $w = 26.4978$ Hz, $w_n = 4.219$ rad/Sec

The table 2: Showing the actual geometrical properties of model.

The mass	0.7438032 Kg
The stiffness	1144.8641 N/m
The natural frequency	4.219 red/Sec
The damping ratio	0.00183

From these calculations above, it can be seen that the D - structure was oscillating in the natural frequency 4.219 rad/Sec, and ζ = 0.00183. Therefore, it would be good enough to see a body excitation with range -5, 5 on the computer, and also it can be helpful to manipulate in the weight of the model mass. Hence the body was developed to one degree of freedom which the weight of the body mass is 0.7438032 Kg, and stiffness 1144.8641 N / m.

After having all data, the empirical values of experiment of the body aero dynamic galloping were represented in several response curves between flow velocities and the amplitudes and in the various attack angles, so the analysis of the D- section excitation are explained based on the body case in this experiment. In general, the flow velocity increase of air raises of the body oscillation, this concept could be a known thing. However, this work was truly discovered a real behavior for the body vibration when the body was made various responses of oscillation at the same angle, the non-symmetric body, which was subjected to various velocities and in various attack angles, make the amplitude increased with velocities increase in the begun, but at the certain flow velocities, there was some change happened, the amplitude was taken stable behavior as linear behavior that behavior is called a lock - in region as shown in the below figures.

The reason for lock - in region is a vortex - induced oscillation accompanied by the frequency synchronization with the D- section frequency by vibration, also result of self - excited. The lock - in region phenomenon is clearly examined by study (Sarpkaya 2004, Bearman 1984).

From above a brief statement of the lock - in region phenomenon, the figures will be clearer if they are discussed individually. At the 0^0 angle, which is considered the standard attack angle of D- Section and where the body was installed in front of the wind tunnel with a semi-circle of cross section area, will be compared to all attack angles of D- Section (45, 90, 135, and $180)^0$.

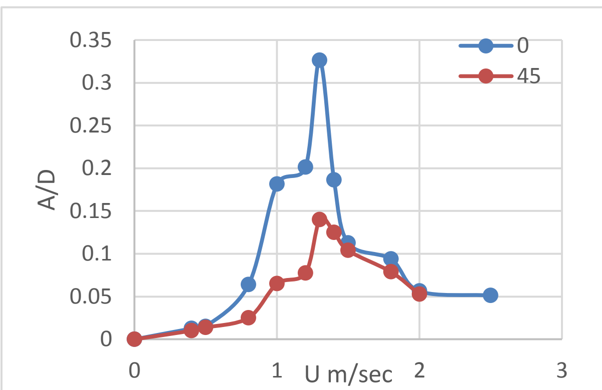

Fig. 3: Shown U versus A/D for angles 0^0, 45^0

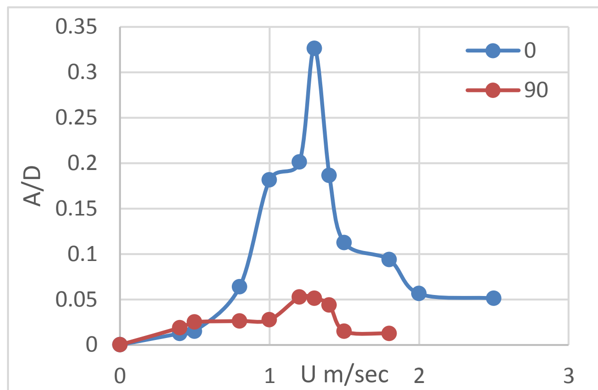

Fig. 4. Shown U versus A/D for the angles 0^0, 90^0.

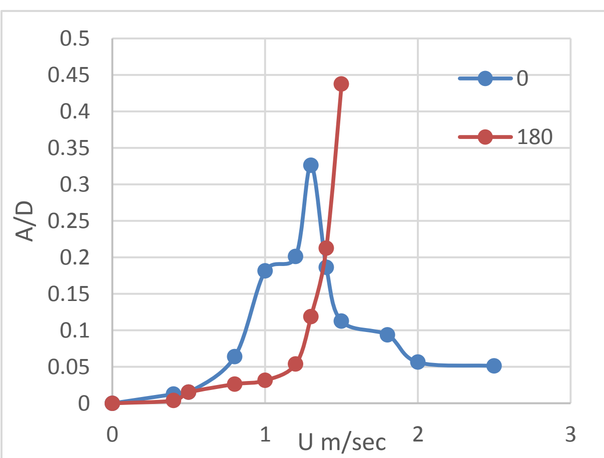

Fig. 5. Shown U versus A/D for angles 0^0, 135^0.

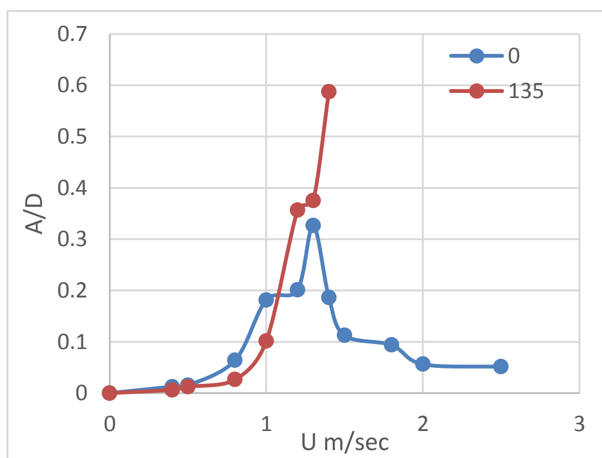

Fig. 6. Shown U versus A/D for angles 0^0, 180^0.

6. Conclusion

The main objective of the analysis presented in the paper is to predict of the effect of various flow velocities on geometrical shapes and specifically on D- Section. Therefore, the attack angle change could have a good effect to decrease the vibration caused by the flow. The D- section is developed from one degree of freedom aero dynamic galloping, and The D- section is a non- symmetric body with the actual geometrical properties are m= 0.7438032 Kg, K= 1144.8641 N/m, the natural frequency 4.219 rad/Sec, and ζ = 0.00183, and the equation of motion which were mentioned in this paper. The prospective suggestions for future to develop this model is to design D- section with small two wings on the both sides of the model with width no more than a quarter of the radius of the model. For example, if the diameter of the model D = 8 cm, the wings measurement width are 1 cm. these wings should be filled with holes to avoid the vortex shedding and the galloping. In conclusion, D- section is used to the design of a building or industrial tools for the big cross- section areas need the expectation of the flow induced vibration an elastic - structure.

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