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Safety analysis on a vibrating prismatic body: A data-mining approach

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ABSTRACT

In this paper, the flow-induced oscillation of a prismatic body, viz., a square section cylinder (test cylinder) under interference conditions is analysed considering it as representing a typical building structure. The analysis is carried out using a data-mining tool called 'Decision Tree' mainly in view of assessing the safety of the structure (test cylinder) with respect to the vibratory amplitude. To achieve this aim, wind tunnel studies have been conducted on the vibratory response of the test cylinder when it is vibrating in the vicinity of another square cylinder (interfering cylinder) which is placed at various locations relative to the test cylinder. The amplitude data thus obtained is suitably classified to carry out the safety analysis. All the data gathered pertains to at a single value of reduced velocity (10.0). Experiments have been carried out for various size ratios (b/B) of the test cylinder (upstream structure) and the interfering cylinder with values of 0.5, 1.0, 1.5 and 2.0. The results indicate that, for certain combinations of the parameters – relative position (L/B, T/B) and size ratio (b/B), the upstream structure could vibrate with high amplitudes making the structural environment 'critical' (unsafe). In practical situations (such as in the case of tall buildings), the critical combinations of these parameters could be identified and eliminated for ensuring structural safety. Parametric combinations ensuring safe structural condition are also identified. Decision Tree also brings out the order of importance of various parameters influencing the interference excitation of the structure (test cylinder); L/B is shown to be the most influencing parameter. The results also show that, for $L/B > 3.0$, there is a higher possibility for the structure to become unsafe when compared to the conditions at $L/B \leqslant 3.0$.

1. Introduction

Flow around bluff bodies at sufficiently large Reynolds number could give rise to the phenomenon called flow-induced vibration due to the periodic shedding of vortices from either sides of the body. As flow takes place over a bluff body, flow separates from the wider section of the body developing free shear layers, which curl and form alternate vortices which once grown to their full size (on reaching saturation), are shed downstream. This vortex shedding process would give rise to fluctuating pressure forces to act on the body and if the body is flexibly mounted, it would undergo vibrations. Such vibrations are characterized by a feed-back mechanism between the vibrating body and the flow field around it (Bishop & Hassan, 1964) and this coupling is understood to be highly non-linear in nature. There are many potential areas of occurrence of this phenomenon such as in heat exchangers, cooling towers, buildings, and bridges.

Square section (a form of rectangle) forms the basic geometry for many real life structures such as buildings and bridges and due to their scope in such practical applications, it has attracted serious research attention in the past and also at present. An interesting feature of this section is that, even in isolated condition, it could be subjected to a variety of fluid–elastic excitation mechanisms including galloping. Literature shows that investigations reported on isolated square cylinder discuss various aspects such as the vortex shedding characteristics and underlying mechanism (Ajith Kumar & Lakshmana Gowda, 2005; Cheng, Zhou, & Zhang, 2003; Laneville & Zhiyong, 1983), velocity and pressure distribution around it (de Grenet & Ricciardelli, 2004; Ko, You, & Kim, 2005; Wienken, Stiller, & Keller, 2006), near-wake characteristics (Dutta, Muralidhar, & Panigrahi, 2003; Ongoren & Rockwell, 1988), aerodynamic forces acting on a square section and their control (Bearman & Luo, 1988; Gu & Peng, 2002; Tamura & Miyagi, 1999) and on the vibratory response characteristics (Gowda & Ajith Kumar, 2006; Robertson, Li, Sherwin, & Bearman, 2003; Wang & Zhou, 2005).

In many practical situations (applications), it is difficult to locate structures in isolation and generally, they are constructed in groups where one structure is located in close proximity with another one (for example, buildings in metro-cities). Also, these structures (especially tall structures in open terrains) could be subjected to the action of high speed winds which could give rise to

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Nomenclature

a	peak-to-peak amplitude
B	side dimension of the test cylinder
b	side dimension of the interfering cylinder
f	fundamental natural frequency of the spring-cylinder system
k_s	Scruton number: mass-damping parameter ($2m\delta/\beta B^2$)
L	longitudinal spacing between axes of cylinders
m	mass per unit length of the test cylinder
T	transverse spacing between axes of cylinders
U	free stream velocity
ρ	density of air
δ	logarithmic decrement

significant aerodynamic interference between them. The magnitude of fluid–elastic excitations occurring in such interference situations would possibly be alarmingly large when compared those occurring in isolated structures and would even lead to large elliptical oscillations (Bailey & Kwok, 1985). As a matter of public comfort and safety, possibility of occurrence of these large amplitude vibrations should be prevented or at least controlled. Hence, it is of great practical importance to understand and analyze the aerodynamic characteristics of a square cylinder (structure) under such interference conditions to properly plan the structural environment. Under interference conditions, besides flow velocity and relative position, size ratio is reported to be of considerable significance in deciding the vibratory response of a square cylinder (Ajith Kumar & Lakshmana Gowda, 2006; Taniike & Inaoka, 1988). Investigations by Takeuchi and Matsumoto (1993), Liu and Chen (2002)), and Schneider and Farge (2005)) also reveal some the interesting features of interference excitation. Unfortunately, in none of these studies reported, the flow-induced vibration data presented are analysed with respect to structural safety. This vacuum in the literature has caused a serious concern to these authors and felt that, such an attempt to assess the structural safety is necessary, it being very relevant from practical point of view. It is to be pointed out that, in the case of circular geometry (for which the applications are much wider) also, the scenario is not different. This paper is primarily intended to fill this gap and contribute a first-hand study on structural safety utilizing a square section cylinder chosen to represent a typical building structure.

In the present investigation, the interference effects on the flow-induced oscillations of a square section cylinder (test cylinder, side dimension B) due to another square cylinder (interfering cylinder, side dimension b) have been recorded (in the form of non-dimensional amplitude vs reduced velocity) and these data have been analyzed using a data-mining tool called 'Decision Tree'. Interference effects have been studied on the test cylinder for various relative positions of the interfering cylinder and for four different size ratios ($b/B = 0.5$, 1.0, 1.5 and 2.0; Fig. 1). All the tests were performed at a single value of reduced velocity (10.0) and at a single value of Scruton number (3.2). Relative position of the interfering cylinder with respect to the test cylinder covers tandem, side-by-side and staggered arrangements (Fig. 1).

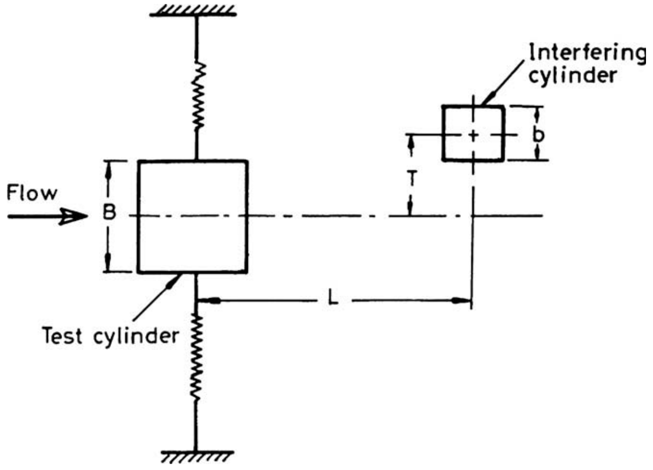

Fig. 1. Schematic sketch of the configuration tested.

It is to be specifically mentioned that, some of the results presented in this paper were reported earlier (Ajith Kumar & Lakshmana Gowda, 2006) (hereafter referred to as A&G). But in A&G, the results are presented in a different form and with an entirely different perspective. In A&G, even though the interference effects are discussed in general, the data are not synthesized to bring out the aspect of structural safety (with respect to excitation amplitude) which is very crucial from the practical point of you, whereas, this is the sole aim of the present investigation and analysis. It is to be highlighted that, it is practically relevant to understand the most critical as well as the safest conditions of structures. As mentioned earlier, such an attempt is not seen in the literature. To fill this gap, on the flow-induced vibration data obtained through interference studies, a data analysis is performed using a data-mining tool called 'Decision Tree' and the results are presented with a new perspective.

It is pointed out that, in the present investigation, the flow-induced vibratory amplitude of the test cylinder (square cylinder) is found to vary significantly with parameters involved such as the relative position of the interfering cylinder with respect to the test cylinder and the size ratio. Hence, in order to get the influence of these parameters on the cylinder excitation amplitude level and thus to assess the structural safety, amplitude is appropriately classified in to four different levels (or classes) depending on the magnitude (Table 1). Then the data analysis is performed using the classifier 'Decision Tree'.

2. Experimental set up

The experimental facility is essentially the same as that used by Gowda and Deshkulkarni (1988) and Gowda and Prabhu (1987) and is shown in Fig. 2. The experiments were conducted on an aluminium tube with a square cross section of side 12 mm, wall thickness 1 mm and length 140 mm. The cylinder was positioned vertically at the centre of a rectangular frame supported by four springs (Fig. 2b). The frame was positioned in front of an open circuit wind tunnel with a square exit duct measuring 120 mm × 120 mm such that the cylinder was at a distance of 44 mm from the exit of the tunnel. The velocity is uniform over the 70% of the exit cross section (variation is less than 1%) and reduces gradually towards the edges.

Table 1
Classification of vibratory amplitude and the structural safety conditions assigned

SI. No.	Class of amplitude	Structural safety	Range of a/B
1	Low (L)	Safest	$a/B \leqslant 0.25$
2	Intermediate (I)	Safe	$0.25 < a/B \leqslant 0.325$
3	Higher (H)	Marginally Safe	$0.325 < a/B \leqslant 0.38$
4	Critical (C)	Unsafe (critical)	$a/B > 0.38$