Reducing flow induced building vibration by streamlining

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Abstract: In this study, experiments are conducted to explore the possibility of flow streamlining to reduce flow induced vibrations of building and structures by placing a smaller circular cylinder downstream of a larger one. A water table flow visualization facility is used in this study. The diameter ratio varies from 1.25 to 6.25 and the Reynolds number based on the diameter of the larger cylinder is either 356 or 890. The results show that flow streamlining of the larger cylinder can be achieved and vortex shedding from the upstream cylinder can be shifted to the downstream cylinder. Furthermore, the Strouhal number of the upstream cylinder can be reduced. The extent of shedding frequency reduction depends on the diameter ratio. In addition, the asymmetric vortex shedding pattern of an isolated cylinder can be altered to a symmetric shedding pattern. Thus, flow-induced vibration can be further reduced.

Key words: streamlining circular cylinders, reducing vortex shedding, flow visualization

1. INTRODUCTION
Flow-induced building vibration is of great concern to building comfort and safety in windy conditions. The collapse of Tacoma Narrows Bridge (Washington, USA) in 1940 and Cooling Towers (Ferrybridge, UK) in 1965 are two lessons learned from wind-induced damages. As buildings are bluff bodies aerodynamically, shedding vortices are a natural consequence [1, 2]. Bluff bodies of simple geometries, such as circular cylinders, rectangular cylinders and tapered cylinders, have been studied for their vortex shedding behaviors. The parameter commonly adopted for describing the vortex shedding behavior is the Strouhal number, e.g. [3]. Because of the potential damages for buildings and structures associated with shedding vortices, methodologies have been developed to reduce the wind-induced vibrations. For example, in practical applications, spiral stakes have been used to reduce flow-induced vibrations for off-shore structures [4, 5] and chimneys. For circular cylinders, Zdravkovich categorized three types of suppression methods, including surface protrusions to change separation points and shear layers, surrounding grids, and splitter plates or guide vanes. By the same token, Wong and Kokkalis [7] further suggested strakes as vortex suppressors; same as Chou, et al [8]. For flows with low

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In this study, a streamlining mechanism is used to reduce flow-induced vibrations of building and structures.

2. EXPERIMENTALLY APPROACH
The streamlining effect is explored experimentally using a pair of circular cylinders with diameter ratios ranging from 1.25 to 6.25. The cylinders are installed in a water table flow visualization facility in an in-line configuration with the larger cylinder upstream of the smaller one. The water table is a continuous flow type with a dimension of 140 cm long x 30 cm wide and 16 cm high of water. Dye flow visualization and limiting streamlines techniques are used to observe the flow. Flow structures are recorded by a digital video camera for further analysis. The upstream larger cylinder has a diameter of either 10 cm or 25 cm, depending on the Reynolds number, while the downstream cylinder has diameters of 2 mm, 4 mm, 6 mm and 8 mm, respectively. Thus, the Reynolds number based on the diameter of the larger cylinder is either 356 or 890. The gap between the two cylinders, denoted by G, is varied so that wake interactions can be explored. The diameters of the larger and smaller cylinders are represented by D and d, respectively.

3. RESULTS AND DISCUSSION
Figures 1 and 2 depict the distributions of Strouhal number versus G/d for D/d of 1.25 and 2.5, respectively. The Reynolds numbers for both figures are 356. Several features can be deduced from the results shown in these two figures. First, when the gap is very small, the larger cylinder becomes a shelter to the downstream cylinder and vortex shedding occurs only for the upstream cylinder. Then, as the gap increases beyond the sheltering range, the two cylinders act as a single cylinder and vortex shedding occurs only from the downstream cylinder. In this range, the Strouhal number decreases. The reduction of Strouhal number increases as D/d increases. In addition, the extent of this range also increases as D/d increase. Finally, as G/d increases farther, both cylinders shed vortices and the Strouhal number of the upstream cylinder returns to the value of an isolated cylinder. In addition to the reduction phenomena described above, the vortex formation length exhibits a general trend of elongation by the presence of a downstream cylinder. This is especially true when vortex shedding occurs from only the downstream cylinder.
Another interesting phenomenon about the vortex shedding pattern is shown in Fig. 3 for which the Reynolds number is 890 and D/d is 6.25. It is well-known that vortex shedding from a circular cylinder is asymmetric. Thus, flow-induced vibration occurs. In the presence of a downstream cylinder, the asymmetric vortex shedding pattern can be modified. As shown in Fig. 3, vortex shedding from the upstream cylinder is fairly symmetric. The picture shown in Fig. 3 is an instantaneous flow pattern. The flow structure tends to switch back-and–forth between the symmetric and asymmetric patterns. Fig. 4 shows the ratio of time occupied symmetric shedding pattern to the total observation time. It can be seen that the ratio oscillates between 20% and 50% when G/d is larger than about 5.7. In other words, the presence of a downstream cylinder not only can reduce upstream vortex shedding frequency can be reduced but also the pattern can be altered. As symmetric vortex shedding pattern can avoid flow-induce vibration along the cross-wind direction, this observation is of interest to practical applications.

4. CONCLUSION
In this study, flow visualization experiments are conducted to explore the possibility of flow streamlining to reduce flow induced vibrations of building and structures by placing a smaller
circular cylinder downstream of a larger one. Key results are summarized as follows: First, flow streamlining of the larger cylinder can be achieved and vortex shedding from the upstream cylinder can be shifted to the downstream cylinder by adjusting the gap between them. Furthermore, the Strouhal number of the upstream cylinder can be reduced. A larger diameter ratio will not only give a larger reduction but also a larger range of gap where shedding reduction can be achieved. In addition, the asymmetric vortex shedding pattern of an isolated cylinder can be altered to a symmetric shedding pattern. Thus, flow-induced vibration can be further reduced.

References