A WIND TUNNEL INVESTIGATION OF A LIQUID COLUMN VIBRATION ABSORBER

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1. INTRODUCTION

Tuned mass vibration absorbers which utilise the viscous interaction between a fluid and solid boundary to dissipate and absorb energy have been found to be very effective in controlling the vibrations of structures in experimental studies when subjected to sinusoidal loading. Two examples of this type of vibration absorber are the Tuned Liquid Column Damper (TLCD) proposed by Sakai et.al.[1], and the Liquid Column Vibration Absorber (LCVA) investigated by Watkins[2], and Watkins and Hitchcock[3],[4].

As a natural progression from the sinusoidal testing procedure, it is desirable that the effectiveness of the vibration absorber should be investigated when it is subjected to the more practical case of random loading. Such a case has been treated in numerical studies, to a certain extent, by Xu et.al.[5],[6] and Sun et.al.[7] for TLCDs. These studies have indicated that the TLCD has the potential to provide additional damping to a tall and slender structure and hence to reduce the magnitude of wind induced vibrations.

Facioni et.al.[8] demonstrated that wind tunnels can be used to determine the effectiveness of supplementary damping devices, and can even allow optimisation of these devices when subject to wind excitation. Consequently, it was decided that a preliminary study would be undertaken to investigate the LCVA under similar conditions. This study allowed the potential of the LCVA to be demonstrated in controlling wind induced vibrations in the cross-wind direction of a model building, particularly at lock-in and galloping excitations, in both tuned and deliberately untuned configurations.

Furthermore, the study also allowed a direct comparison to be made between a LCVA and a Tuned Liquid Damper (TLD) in free-vibration tests of the building model, in which the masses of both devices, and the free-vibration frequency of the LCVA and the liquid sloshing frequency of the TLD, were the same.

2. EXPERIMENTAL SET-UP

2.1 Wind Tunnel

The LCVA was installed in a rectangular model building and tested in the No.1 Boundary Layer Wind Tunnel at the School of Civil and Mining Engineering, the University of Sydney. The wind tunnel used was an open circuit type with a 2.4m x 1.8m working section. A Terrain Category 3 wind profile was generated in accordance with the Australian Wind Load Code (AS1170.2-1989)[9] by a combination of spires and roughness blocks over a 12m fetch length of working section. The model building used in the experimental program was a 1:100 scaled aeroelastic model of rigid construction with properties as listed in Table 1. The model was mounted on a single degree of freedom translational aeroelastic testing rig with strain gauges mounted to monitor the model's dynamic behaviour. The system was designed so that the model would only vibrate in one translational mode with a linear mode shape.

2.2 Model LCVA And TLD

The Liquid Column Vibration Absorber (LCVA) designed for the experiments in this paper is illustrated in Figure 1. The system developed was a uni-directional device designed to suppress cross-wind building vibrations. The LCVA was constructed of perspex with a horizontal length of 230mm and a width of 100mm. The horizontal and vertical columns were designed with equal thicknesses of 15mm. The device was filled with water and was tuned by adjusting the liquid column depth "l". The mass of the liquid was approximately 1.9% of the first mode generalised mass of the structure.

The Tuned Liquid Damper (TLD) incorporated into the experiments was a simple variation on the design of the LCVA as shown in Figure 1. The LCVA had an interior chamber which when filled with water created a TLD. The TLD was also uni-directional designed to reduce the cross-wind building vibrations. The TLD had a length of 180mm and a width of 100mm. The adjustment of the liquid depth tuned the system. The mass of the liquid was also approximately 1.9% of the first mode generalised mass of the structure.

3. EXPERIMENTAL PROGRAM

Before any wind tunnel tests were carried out on the LCVA or TLD, the total structural damping of the model building with either device installed was measured by means of free vibration decays. From the decays it would be possible to determine which device was more effective in increasing the total structural damping of the model building. The physical properties of each device are listed in Table 2. Both devices were tuned to the natural frequency of the model building.

The LCVA was then installed in the model building and tested in the wind tunnel for its ability to suppress wind-induced building vibrations. The model building was aligned with its wide face normal to the wind direction allowing the analysis of the cross-wind mechanisms. The normalised standard deviation cross-wind top floor displacement responses of the building model were measured at reduced velocities ranging from 4 to 16 for the cases of no control and control with the LCVA installed. The effectiveness of the device in the extreme case of the building experiencing galloping excitation was also investigated. For this case the test was carried out at a reduced velocity of 33.

The effect of varying the tuning of the LCVA by altering the vertical liquid column depth was also investigated. The total structural damping of the model building was determined by free vibration decay curves. Six different tuning ratios of the LCVA were investigated. The LCVA properties for each tuning are listed in Table 3.

Finally, a comparison was made between the effectiveness of the LCVA with a tuning ratio of 1 and the LCVA with a tuning ratio of 1.06. The intention of the comparison was to see if the LCVA with a tuning of 1.06 was still effective when subject to wind induced vibrations. For the comparison, the normalised standard deviation cross-wind top floor displacement responses of the building model were measured at reduced velocities ranging from 4 to 16 for the three cases of no control, control with the LCVA tuning at 1.0 and finally control with the LCVA tuned at 1.06. The response signals were also recorded for spectral analysis.

4. EXPERIMENTAL RESULTS

The free vibration decay curves for the model building with no control, control with the LCVA installed and finally control with the TLD installed are presented in Figures 2 (a) to (c). Both the LCVA and the TLD had the same mass and tuning. The installation of either of the control devices increased the total structural damping of the model building. The LCVA was observed to be superior to the TLD in terms of increasing the structural damping. The LCVA increased the total structural damping by 3.2% of critical damping, whereas the TLD increased the total structural damping by 2.5% of critical damping.

The cross-wind response results for the model building with no control and with LCVA installed are presented in Figure 3. The figure presents the normalised standard deviation top floor cross-wind displacement response σ_y/b versus reduced velocity. σ_y represents the standard deviation cross-wind top floor displacement response of the building and b is the width of the building normal to the wind. The LCVA was effective in suppressing cross-wind building vibrations in the velocity range tested. At a reduced velocity of 10 the building with no control was observed to experience lock-in excitation. The addition of the LCVA significantly reduced the structural response and eliminated the lock-in phenomenon. At a reduced velocity of 10 the LCVA reduced the cross-wind response of the model building by 85%.

Time history traces for the top floor displacement of the model building with no control and with LCVA control are presented in Figure 4. The traces were taken at a reduced velocity of 33 for the extreme case of the model building experiencing galloping excitation. The traces show that the LCVA is successful in suppressing the galloping mechanism. The standard deviation displacement response was reduced by 75%.

With the effectiveness of the LCVA established, the task was undertaken to investigate what effect altering the tuning of the liquid had on the performance of the device. Figure 5 plots the total structural damping of the model building with the LCVA installed against the tuning frequency of the LCVA. As is illustrated in the figure, the tuning of the LCVA has an important influence on how the device performs in increasing the total structural damping of the model building. The optimum tuning was found to be at a tuning ratio of 1.02, in which case, the LCVA increased the structural damping to over 4.4% of critical.

The cross-wind response results for the model building with no control, control with the LCVA {tuning ratio of 1.0} installed and finally control with the LCVA {tuning ratio of 1.06} installed are presented in Figure 6. The LCVA with a tuning ratio of 1 or 1.06 will be referred to as tuned or untuned, respectively. The untuned LCVA was found to be almost as effective as the tuned LCVA in suppressing wind-induced cross-wind building vibrations in the velocity range tested. The untuned LCVA significantly reduced the structural response at a reduced velocity of 10 and eliminated the lock-in phenomenon. A similar observation was made earlier for the tuned LCVA. At a reduced velocity of 10 the tuned LCVA reduced the cross-wind response of the model building by 85%, whereas the untuned LCVA reduced the cross-wind response of the model building by 82%. In the reduced velocity range below a reduced velocity of 10 there was little difference between the performance of the two LCVA cases. The performance of the untuned LCVA dropped off a little in the reduced velocity range beyond a reduced velocity of 10.

The results of spectral analyses at a reduced velocity of 10 for the model building with no control, control with the LCVA {tuning ratio of 1} installed and finally control with the LCVA {tuning ratio of 1.06} installed are presented in Figures 7 (a) to (c). The model building with no control has a large peak at the natural frequency of the model building. Clearly the installation of the LCVA reduces the peak in the spectrum. In fact, the peak is reduced so much that there is slightly more energy from the frequencies just around the peak. The reason for the large reduction in the peak is due to the effect the increase in total structural damping has on the mechanical admittance function of the model building. Both the tuned and untuned LCVA systems are very similar in the way they achieve the reduction in building response.

5. CONCLUSIONS

The preliminary investigation into the effectiveness of an LCVA in suppressing wind-induced building vibrations at a small model scale has been found to be successful. The following general conclusions can be made.

1) The installation of the LCVA into the model building is more effective than the installation of the TLD in terms of increasing the total structural damping. As expected, an increase in structural damping resulted in a decrease in the response of the structure when subjected to wind loadings.

2) The LCVA was effective in reducing the cross-wind response of the model building. The LCVA was observed to limit the effects of certain mechanisms such as lock-in and galloping.

3) Varying the depth of the vertical column of liquid altered the tuning ratio of the LCVA which in turn changed the total structural damping of the structure.

4) If a LCVA becomes untuned it can still be expected to give a substantial reduction in the wind-induced response of the structure.

This wind tunnel investigation of the LCVA is at a very early stage of development. The results presented in this paper show that there is promise in such an investigation. This paper paves the way for further research into this area.

References

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Dimensions	0.2x0.3x1.1m
Mass (M)	79.78kg
Generalised Mass (m_1)	26.59kg
Frequency	1.29Hz
Structural Damping	0.56% of critical

Table 1 Model Building Properties

Device	LCVA	TLD
Mass (m_2)	510g	520g
Mass Ratio (m_2/m_1)	1.9%	1.9%
Liquid Frequency	1.26Hz	1.27Hz
Frequency Tuning	1	1

Table2 LCVA/TLD Properties

Frequency Tuning Ratio	Liquid Mass	Vertical Liquid Column	Liquid Frequency
0.95	560g	87mm	1.20Hz
0.97	537g	79mm	1.22Hz
1.00	510g	70mm	1.26Hz
1.02	483g	61mm	1.28Hz
1.06	460g	54mm	1.33Hz
1.07	444g	48mm	1.35Hz

Table 3 LCVA Tuning Properties

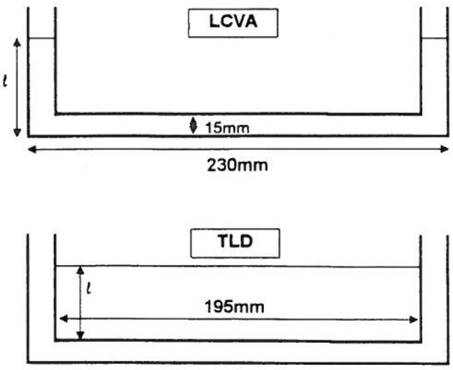

Figure 1 Experimental Device

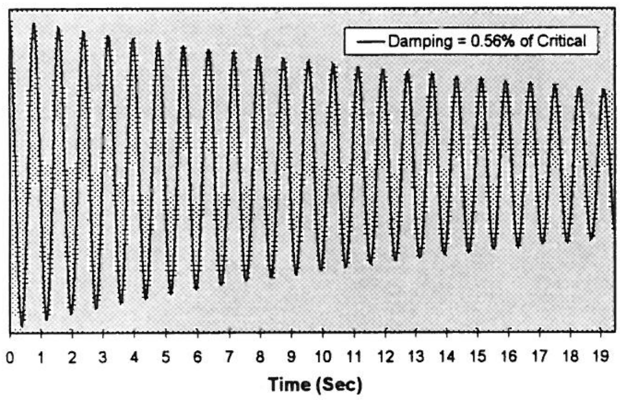

Figure 2a Building Decay No Control

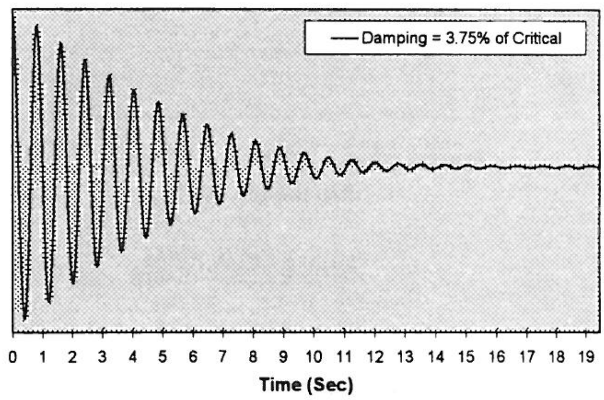

Figure 2b Building Decay LCVA Control

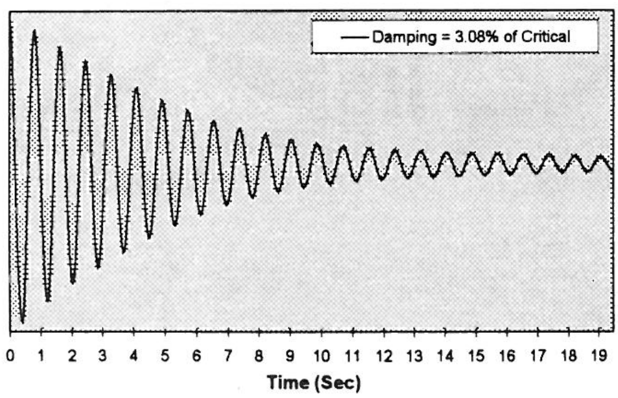

Figure 2c Building Decay TLD Control

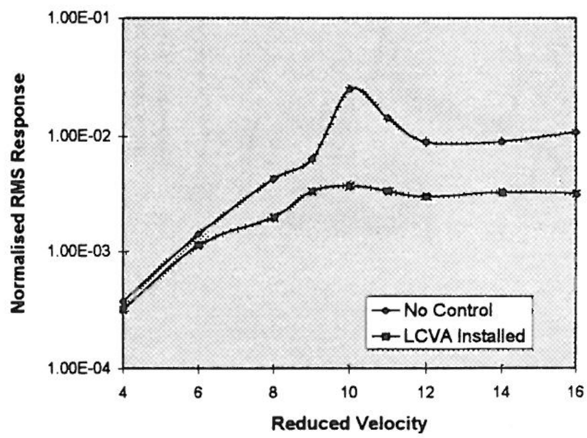

Figure 3 Cross-Wind Response With LCVA Installed

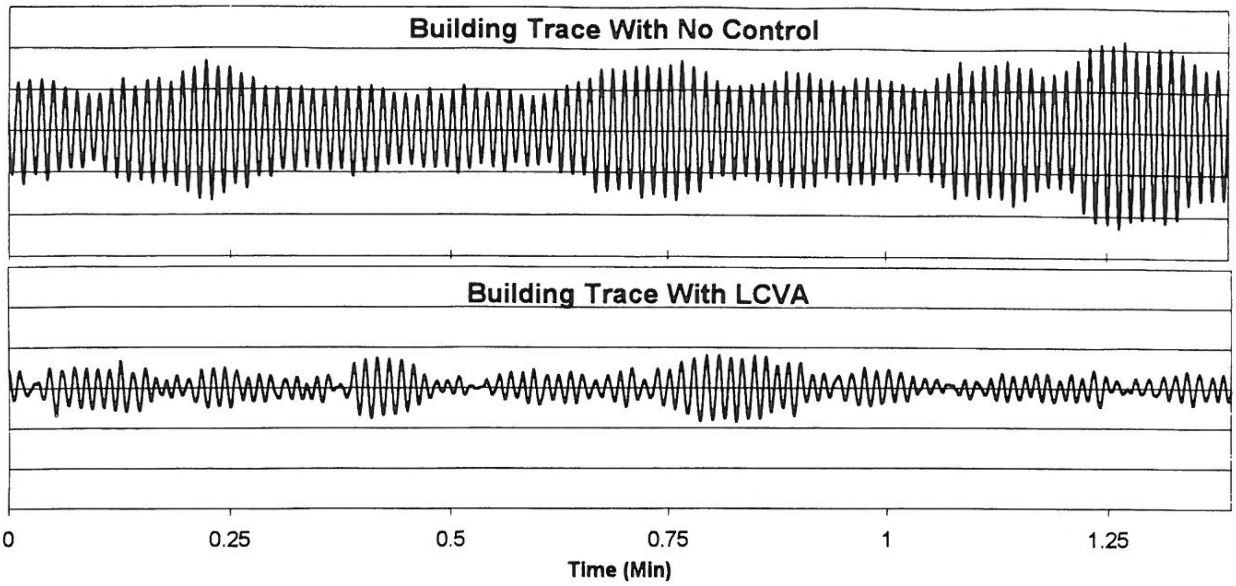

Figure 4 Reduced Velocity 33 Trace

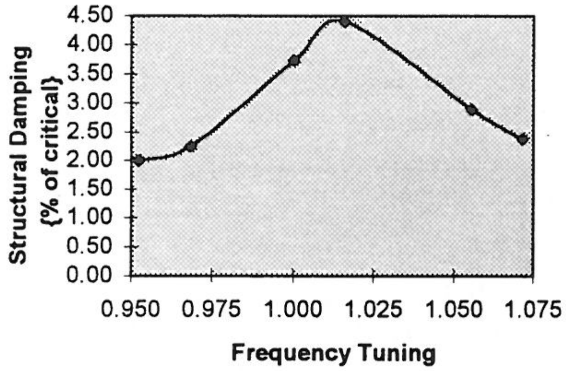

Figure 5 LCVA Tuning

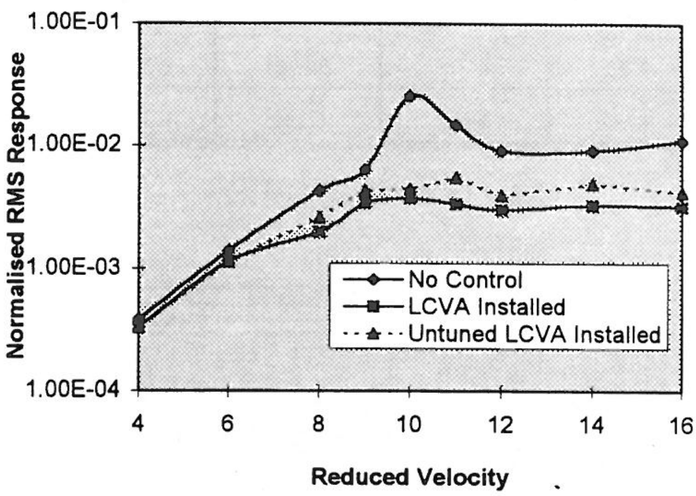

Figure 6 Cross-Wind Response

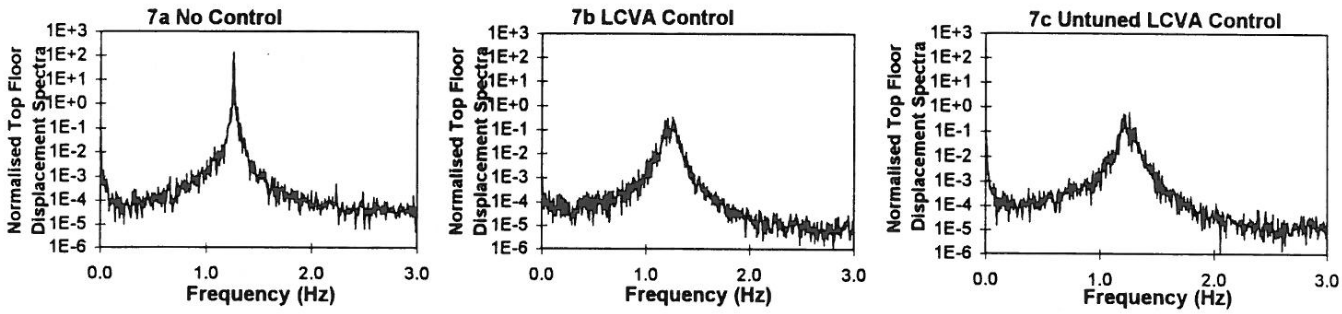

Figure 7 Top Floor Displacement Spectra