EXPERIMENTAL INVESTIGATION OF A CIRCULAR LCVA

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1. INTRODUCTION

Advances in design and construction techniques have allowed the construction of lighter and taller buildings that can be occupied relatively quickly. Modern tall buildings are also more susceptible to excessive wind or earthquake induced vibrations because of their increased flexibility and low intrinsic damping. These excessive vibrations may cause occupant discomfort, cracking of cladding or partitions and even structural failure during strong environmental events. Furthermore, asymmetrical tall buildings with an eccentricity between the mass and shear centres may cause both lateral and torsional modes of vibration to be significant. However, the number of studies concerning torsion vibration control are limited to a proposed Tuned Mass Damper (TMD) system to control both lateral and torsional vibration [1].

A variety of vibration absorbers have been studied to control environmentally induced tall building vibrations [2 - 4]. Each type of vibration absorber investigated has certain advantages and disadvantages, and a suitable choice of vibration absorber should satisfy the various performance, architectural, economical and legislative criteria of a specific structure. One recently investigated vibration absorber, a Liquid Column Vibration Absorber (LCVA), is a passive vibration absorber comprised of vertical and horizontal liquid columns which may have different cross-sectional areas, depending on performance requirements. LCVA studies conducted at the University of Sydney [5, 6], and a full-scale LCVA application [7], have concentrated on developing a vibration absorber to control lateral along-wind and cross-wind vibrations.

In this study, a circular LCVA is investigated in free and forced vibration experiments to determine its effectiveness to control purely torsional vibrations. The circular LCVA design is based on that of a conventional rectangular LCVA system used to control lateral vibrations. The natural frequency of a circular LCVA may be easily altered by altering its effective length of liquid column to tune the vibration absorber to a structure's natural frequency.

2. CIRCULAR LCVA AND TORSIONAL SHAKE TABLE CONFIGURATION

The circular LCVA comprised two separate liquid columns accommodated in a tubular container, which was located on the shake table as shown in Figure 1. The liquid column had a constant rectangular cross-section throughout, having dimensions of 40 mm × 40 mm. The diameter of the circular LCVA was 820 mm. As with traditional LCVAs and Tuned Liquid Column Dampers (TLCDs), the liquid damping ratio of a circular LCVA can be controlled by the inclusion of orifices in the horizontal columns. As no orifices were installed for the experiments reported here, the liquid damping ratio of the circular LCVA was expected to be less than optimum. The LCVA liquid damping ratio varied between approximately 3% and 5% of critical damping depending on the vertical column height, which is denoted as h_v in Figure 2.

The natural frequency of a LCVA (n) is presented in Equation (1)

$$n = \frac{1}{2\pi}\sqrt{\frac{2g}{L_E}} \qquad (1)$$

where;
g = gravitational acceleration
L_E = liquid column effective length
and liquid column effective length is defined by Equation (2)

$$L_E = \left(\frac{A_v}{A_h}\right).d + 2h_v \qquad (2)$$

where, in Figure 2;
A_v = vertical column cross-sectional area
A_h = horizontal column cross-sectional area
d = horizontal column length
h_v = vertical column height
As A_v, A_h are equal, and d is fixed for the circular LCVA studied here, the liquid column effective length could only be varied by varying the vertical column length (h_v).

The shake table used for this experimental investigation comprised a wooden platform located on a low friction bearing to restrict the platform to torsional vibrations only. The total mass of the shake table was 145 kg, having a moment of inertia of 22.5 kg-m^2. Free-vibration experiments of the shake table without a LCVA installed allowed its torsional natural frequency to be determined as approximately 0.56 Hz, and its damping ratio was determined as approximately 0.75% of critical damping. The torsional natural frequency of the shake table was controlled by extension springs.

The experimental system is presented diagrammatically in Figure 3.

3. EXPERIMENTAL RESULTS

3.1 Free-vibration Experiments

Free-vibration experiments were performed using the shake table installed with a circular LCVA containing fresh water. The LCVA was located so that its centroidal axis coincided with that of the shake table. Vertical column heights of 168 mm, 200 mm and 235 mm were investigated, which correspond to liquid column effective lengths of approximately 1584 mm, 1648 mm and 1718 mm respectively. Ratios of horizontal column length to liquid column effective length (d/L_E) for these vertical column heights were 81.3%, 78.2% and 75% respectively.

For the aforementioned vertical column heights, the total LCVA liquid masses were 5.07 kg, 5.27 kg and 5.5 kg respectively. The ratios of total LCVA liquid mass to total structural mass were approximately 3.5%, 3.63% and 3.8% respectively. LCVA liquid natural frequencies corresponding to these vertical column heights were determined as approximately 0.56 Hz, 0.55 Hz and 0.54 Hz, or 100%, 98% and 96% of the structure's torsional natural frequency respectively. The effective LCVA liquid moment of inertia was 0.693 kg-m^2, so that the ratio of the moments of inertia of LCVA liquid to structure was 3.1%.

Free-vibration experiments were initially conducted on the shake table without a LCVA installed. After displacing the shake table 40 mm beyond its equilibrium position, the shake table was released and allowed to vibrate freely until it came to rest. The results of this free-vibration experiment are presented in Figure 4. Subsequent free-vibration experiments were conducted with the various aforementioned LCVA configurations installed, the results of which are also presented in Figure 4. It is clear that each LCVA configuration significantly increases the capacity of the shake table to dissipate torsional vibrational energy.

Beating phenomenon which can be observed in Figure 4 indicates that the LCVA liquid damping ratio was less than optimum for the LCVA configurations tested.

3.2 Frequency-sweep Experiments

Frequency-sweep experiments were also used to investigate the effectiveness of each circular LCVA configuration. This type of test involves the application of a constant amplitude sinusoidal load to the shake table, and incrementally increasing the load frequency through a range about the shake table's torsional natural frequency. The displacement of the primary structure corresponding to each load frequency was measured. The LCVA configurations studied in frequency-sweep experiments were the same as those studied in free-vibration experiments.

Without a circular LCVA installed, the shake table response is typical of a single degree of freedom system as shown in Figure 5. "Amplitude Ratio" in Figure 5 is defined as the ratio of the dynamic amplitude of displacement of the shake table to the static amplitude of displacement of the shake table. "Load Frequency Ratio" is defined as the ratio of the frequency of the externally applied sinusoidal load to the shake table's torsional natural frequency. The single peak amplitude ratio of the shake table system occurs at a load frequency ratio of approximately one, which corresponds to the shake table's torsional natural frequency.

Also presented in Figure 5 is the frequency-sweep response of the shake table installed with a circular LCVA. The large magnitude resonant peak which occurs for the shake table alone is eliminated by the installation of a LCVA. Two peak amplitude ratios occur with the installation of a LCVA, one occurring at a load frequency ratio less than one, the other at a load frequency ratio greater than one.

A comparison can be made between the effectiveness of each circular LCVA configuration from the frequency-sweep results presented in Figure 6. It can be seen from Figure 6 that as the vertical column height is increased, and the circular LCVA natural frequency is decreased, the effectiveness of the circular LCVA to mitigate vibrations is enhanced for the range of load frequency ratios tested. The presence of two peak amplitude ratios for each circular LCVA installation is a further indication that the LCVA liquid damping ratio was less than optimum for the configurations tested.

4. CONCLUSIONS

The ability of a circular LCVA to mitigate torsional structural vibrations was investigated. The following conclusions can be made from the results:
(1) A circular LCVA is an effective method of controlling torsional vibrations.
(2) Frequency-sweep experiments can be used to demonstrate the effectiveness of circular LCVAs, and can be used to investigate the effects of parameter changes.
(3) The liquid damping ratio of a circular LCVA may be less than optimum for some applications. The inclusion of orifices may increase the liquid damping ratio close to the optimum value, which may be proven by further experiments.
(4) The application of a circular LCVA provided approximately a fourfold increase in the total damping of a torsional mode of vibration of a shake table.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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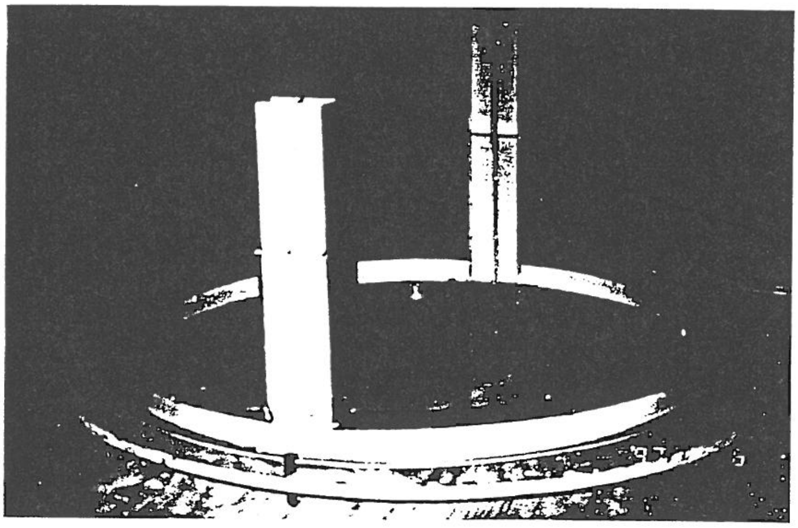

Figure 1. Circular LCVA and Shake Table Configuration.

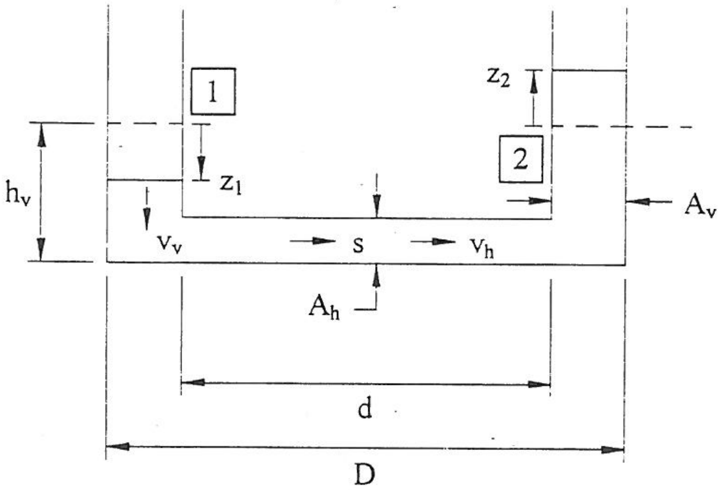

Figure 2. Elevation of a LCVA.

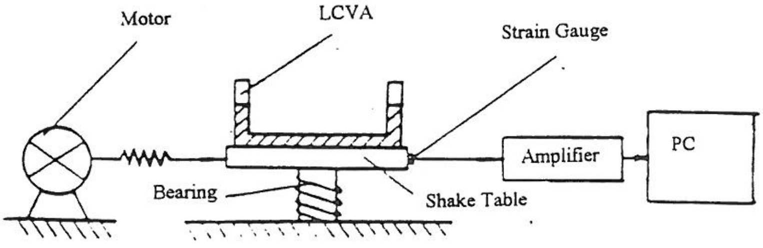

Figure 3. Diagrammatic Representation of the Experimental System.

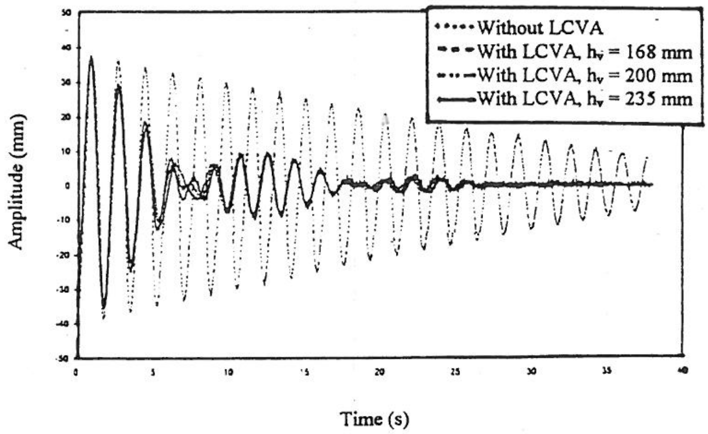

Figure 4. Shake Table Free-vibration Oscillations.

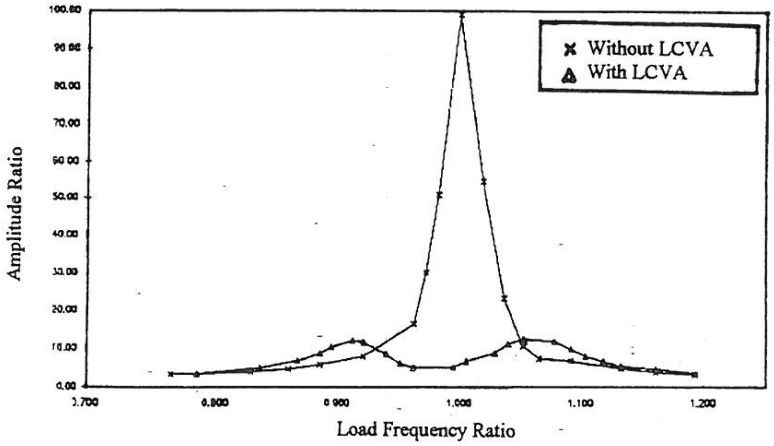

Figure 5. Shake Table Frequency-sweep Response.

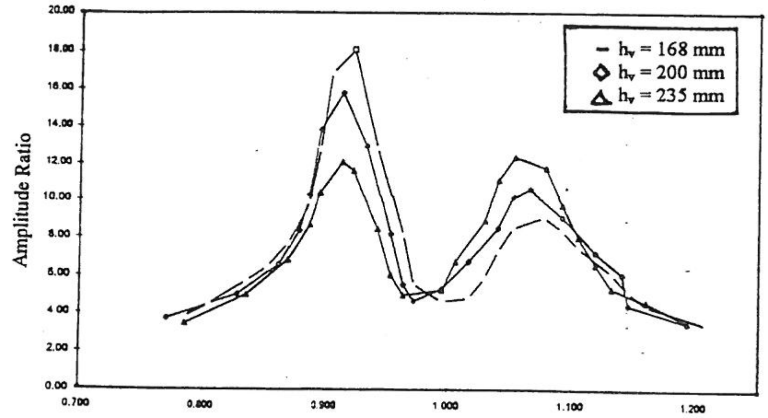

Figure 6. Effect of Circular LCVA Tuning.