EFFECTS OF GEOMETRIC SCALE ON BI-DIRECTIONAL LCVA CHARACTERISTICS

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Abstract

The effects of geometric scale on the characteristics of bi-directional LCVAs were investigated to determine the suitability of the proposed empirical formulae to be applied to larger scale LCVAs. The accuracy of the proposed empirical formula for the estimation of bi-directional LCVA natural frequency was demonstrated to be unaffected by geometric scale. Furthermore, the relationship between natural frequency and geometric scale of bi-directional LCVAs confirmed the analytical studies of Watkins and Hitchcock (1992).

1. Introduction

To date, studies of bi-directional LCVAs have been limited to those of a relatively small scale. However, in practical situations a large bi-directional LCVA may be required for mass, frequency or damping purposes to suppress wind-induced vibration of tall building. In that case, the effects of geometric scale on the prediction of LCVA natural frequencies and liquid damping ratios should be considered during the design process.

In this paper, effects of geometric scale on bi-directional LCVA natural frequencies and liquid damping ratios are further investigated by free-vibration experiments. Four different bi-directional LCVAs are studied, whose the dimensions are summarized in Table 1 and Figure 1 with side lengths of 310mm, 387mm, 774mm, and 1548mm corresponding to geometric scale ratios of 1.0, 1.25, 2.5, and 2.5 respectively.

2. Effects of Scale on LCVA Natural Frequency

Fundamental natural frequencies of LCVA liquid oscillation were determined from free-vibration experiments and plotted with respect to $\frac{h_v}{d_x}$ in Figure 2. In Figure 2, the natural frequencies for all LCVA geometric scale ratios show similar trends for the range of $\frac{h_v}{d_x}$ tested. Moreover, the relationship between geometric scale and LCVA natural frequency for any two scale ratios is presented in Equation (1), which confirms the analytical study of Watkins and Hitchcock (1992).

$$\frac{F_1}{F_2}=\frac{\sqrt{S_2}}{\sqrt{S_1}} \tag{1}$$

In Equation (1), F_1 and F_2 are the fundamental natural frequencies of LCVA liquid oscillation, and S_1 and S_2 are the linear length scales of two different scale LCVAs.

In addition, a comparison of the experimentally measured and predicted bi-directional LCVA natural frequencies are presented in Figure 2. It can be seen from the Figure 2 that fundamental bi-directional LCVA natural frequency can be estimated for the range of LCVAs tested.

Also included in Figure 2 are error bars representing estimated experimental errors of approximately 2% for the free-vibration experiments. The majority of experimental data are within 2% of the predicted LCVA natural frequencies, the exception being for larger values of

$\frac{h_v}{d_x}$, which correspond to larger vertical column heights, for the smaller scale LCVAs tested. This discrepancy is belived to be caused by wave effects in the vertical columns, as reported by Watkins and Hitchcock (1992), and this experimental data is still within approximately 5% of the predicted fundamental natural frequencies.

3. Effects of Scale on LCVA Damping Ratio

Liquid damping ratios for bi-directional LCVAs were extracted from free-vibration experimental results, and presented with respect to Reynolds number in Figures 3 to 7 for $\frac{h_v}{d_x}$ of 0.130, 0.173, 0.216, 0.259, and 0.303 respectively. Reynolds numbers were calculated as the ratio of $\frac{\rho v d_x}{\mu}$. Fresh water was used for each LCVA configuration tested, thereby maintaining constant liquid properties of ρ and μ. Horizontal liquid column length (d_x) was varied to reflect the different geometric scale of each LCVA, and velovity (v) was related to the amplitude of liquid oscillation.

For Reynolds numbers up to approximately 2000, it is expected that viscous interaction between the LCVA liquid and the rigid container would be the dominant mechanism of energy dissipation. This is confirmed to some extent by the straight line relationship between LCVA liquid damping ratio and Reynolds number in Figures 3 to 7 for Reynolds numbers less than approximately 2000. It can also be seen from Figures 3 to 7 that LCVA liquid damping ratios tend towards asymptotic values when Reynolds number increases beyond 2000. This suggests that energy is dissipated by both viscous interaction and turbulant flow, which is induced by sharp corners and baffles, and the transition between the horizontal and vertical columns.

Figures 3 to 7 also confirm that geometric scale is another significant parameter which controls liquid damping ratios of bi-directional LCVAs. It can be seen from Figures 3 to 7 that damping ratio generally decreases with increases of geometric scale. For the smaller geometric scales tested, friction between LCVA liquid and the rigid container is likely to be the dominent mechanism of energy dissipation due to the proportion of LCVA liquid viscously interacting with the solid boundary. This interaction is obviously less for the largest geometric scale LCVA tested, and the measured liquid damping ratio is accordingly lower. Hence, for that LCVA configuration, it is expected that energy would be dissipated by a combination of both viscous interaction and turbulence, and the contribution of turbulence of energy dissipation could be increased by the inclusion of orifices in the horizontal column, as previously studied by Hitchcock (1996).

In general, LCVA liquid damping ratio also increases with respect to $\frac{h_v}{d_x}$. This is thought to be due to a combination of the increased surface area of contact between the LCVA liquid and container, and the likelihood of additional turbulence generated by the baffles. However, increases in liquid damping ratio are less for the two smaller geometric scale LCVAs tested, suggesting that viscous interaction in the horizontal column is the dominant mechanism of energy dissipation for those two LCVAs.

A comparison between experimentally determined LCVA liquid damping ratios and those predicted is presented in Figure 8. It can be seen from Figure 8 that liquid damping ratios are under estimated for the two smallest geometric configurations tested. This is because a formula for the prediction of LCVA liquid damping ratio was derived for larger scale LCVAs, hence with less contribution from viscous interaction to energy dissipation. Significant overestimations of several liquid damping ratios were observed the largest geometric scale

LCVA tested, particulary for very small values of $\frac{Xo}{d_x}$. This is probably because the formula was derived for larger values of $\frac{Xo}{d_x}$. Furthermore, small amplitudes of LCVA liquid vibration (Xo) would generally correspond to small building amplitudes, which are not likely to cause occupant discomfort. Good estimations of liquid damping ratio were achieved for the two largest LCVA configurations, and particulary for larger amplitudes of vibration represented by the parameter $\frac{Xo}{d_x}$.

References

1. Hitchcock, P.A. (1996). Vibration Control of Structures by Liquid Column Vibration Absorber, Ph.D. Thesis, The University of Sydney.
2. Watkins, R.D. and Hitchcock, P.A. (1992). Model Tests on a Two-way Liquid Column Vibration Absorber, Research Report No. R656, School of Civil and Mining Engineering, University of Sydney, August.

LCVA No.	Side Lengths (mm)	$d_x=d_y$ (mm)	$B_{sx}=B_{sy}$ (mm)	$T_{vx}=T_{vy}$ (mm)	T_h (mm)	h_v (mm)
1	310	278	68.5	16	13.6	36-84
2	387	347	86	20	17	45-105
3	774	694	170	40	34	90-210
4	1548	1388	343	80	68	180-420

Table 1. Summary of LCVA Configurations for Study of Effects of Geometric Scales

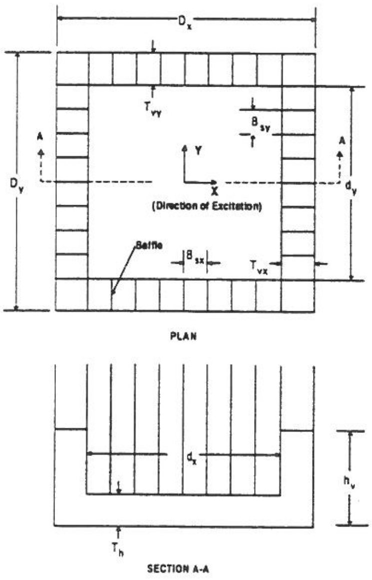

Figure 1. Bi-directional Liquid Column Vibration Absorber (LCVA)

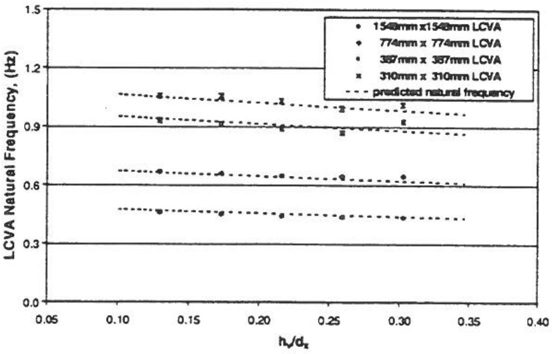

Figure 2. Comparison of Natural Frequencies of Different Scale Bi-directional LCVAs

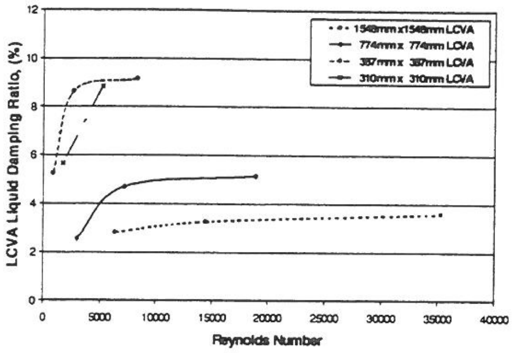

Figure 3. Comparison of Liquid Damping Ratios of Different Scale Bi-directional LCVAs for $\frac{h_v}{d_x}$ of 0.130

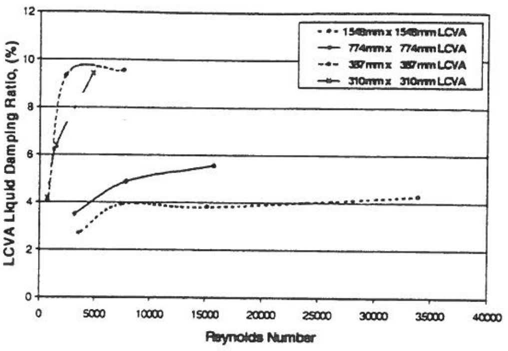

Figure 4. Comparison of Liquid Damping Ratios of Different Scale Bi-directional LCVAs for $\frac{h_v}{d_x}$ of 0.173

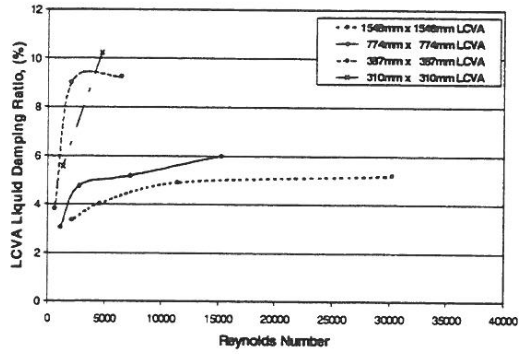

Figure 5. Comparison of Liquid Damping Ratios of Different Scale Bi-directional LCVAs for $\frac{h_v}{d_x}$ of 0.216

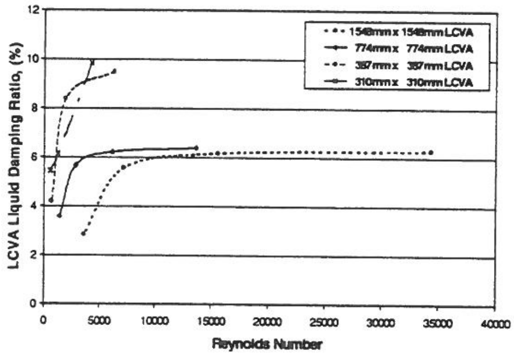

Figure 6. Comparison of Liquid Damping Ratios of Different Scale Bi-directional LCVAs for $\frac{h_v}{d_x}$ of 0.259

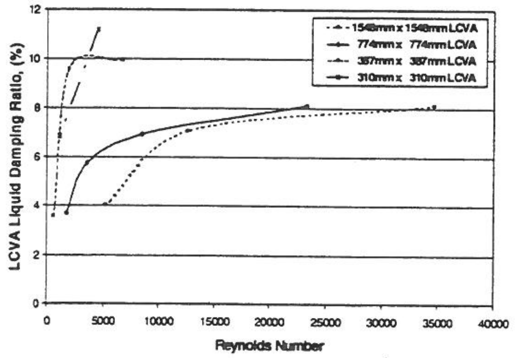

Figure 7. Comparison of Liquid Damping Ratios of Different Scale Bi-directional LCVAs for $\frac{h_v}{d_x}$ of 0.303

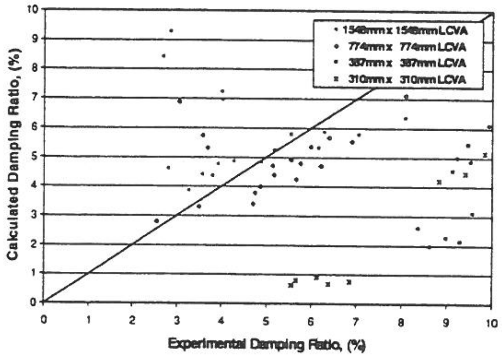

Figure 8. Comparison of Experimental and Predicted Damping Ratios of Different Scale Bi-directional LCVAs