# STUDIES OF A BI-DIRECTIONAL LIQUID COLUMN VIBRATION ABSORBER

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## 1. INTRODUCTION

Wind may cause severe vibrations of large slender structures such as tall buildings. If the vibrations exceed their serviceability or safety limit, energy dissipation devices called vibration absorbers can be installed in the buildings to reduce the undesirable vibration. Many types of vibration absorber have been introduced during the past four decades, including Tuned Mass Dampers, Nutation Dampers, and Tuned Liquid Sloshing Dampers.

Recently, a new type of vibration absorber known as Tuned Liquid Column Damper (TLCD) was introduced by Sakai et al. (1989). That research proposed a number of advantages in this device over other vibration absorbers such as: smaller size, lower cost, less maintenance and easy tuning of the absorber natural frequency. Moreover, the water inside a TLCD can be used for water supply or emergency purposes. Further studies were conducted by Watkins (1991) and Watkins and Hitchcock (1992). According to those papers, new liquid dampers called Liquid Column Vibration Absorbers (LCVA) have the potential to reduce structural vibrations. Hitchcock et al. (1994) proposed a uni-directional Multiple Liquid Column Vibration Absorber (MLCVA), which consisted of a number of LCVAs whose natural frequencies were distributed over a certain range around the natural frequency of a structure. In that study, a MLCVA was found to provide greater reduction of peak structural displacements than a single LCVA, and the nested configuration of a MLCVA is more compact than that of a LCVA. Furthermore, a MLCVA has the potential to be less sensitive to frequency mistuning of a small magnitude which is an important factor when choosing any type of vibration absorber.

The studies of Hitchcock et al. (1997) presented equations to predict natural frequency of a LCVA in terms of geometric parameters and an empirical factor. In this preliminary experimental study, other geometric parameters are considered to estimate the empirical factor. In addition, a more practical water level configuration of MLCVA is proposed.

## 2. EXPERIMENTAL CONFIGURATION

### 2.1 Study of a Bi-directional LCVA

From Hitchcock et al. (1997), the natural frequency of a bi-directional LCVA, as shown in Figure 1, can be predicted from Equation (1).

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

In Equation (1), $L_E$ is called the liquid column effective length and is given by Equation (2)

$$L_E = \alpha_{\rho\eta}\left(\frac{T_{vx}}{T_h}\right)d + 2h_v \qquad (2)$$

where $T_{vx}$ = vertical column thickness orthogonal to the direction of excitation

$T_h$ = horizontal column thickness

$d$ = horizontal column length

$h_v$ = vertical column height

$\alpha_{\rho\eta}$ = an empirical factor

Hitchcock et al. (1991) suggested $\alpha_{\rho\eta}$ was dependent on vertical column ratio ($T_{vy}/T_{vx}$). In this study, free vibration experiments of a 780mm x 780mm bi-directional LCVA were conducted for vertical column heights of 70, 90, 120, 150, 180, 210 and 240 mm. LCVA natural frequencies measured from free vibration experiments were plotted with respect to vertical column height in Figure 2, and compared to calculated natural frequencies using $\alpha_{\rho\eta}$ equal to 1.0 and 1.3, which were suggested by Hitchcock et al. (1997) for bi-directional LCVAs. Obvious discrepancies between experimental and predicted natural frequencies can be observed in Figure 2.

Values of $\alpha_{\rho\eta}$ were extracted from the experimental results and plotted with respect to the ratio of vertical column height to horizontal column length ($h_v/d$). The results can be represented by a straight line of linear regression analysis, as shown in Figure 3. This figure can be used to estimate the natural frequency of a bi-directional LCVA, as represented by the solid line in Figure 2. Thus, $\alpha_{\rho\eta}$ is dependent on the vertical column ratio ($T_{vy}/T_{vx}$) and the ratio of vertical column height to horizontal column length ($h_v/d$).

### 2.2 Study of a Bi-directional MLCVA

A more practical arrangement for a MLCVA may be a common liquid level which is used for the individual liquid columns. This may be advantageous for MLCVA water levels to be controlled by a single controller to facilitate liquid use for sanitary purposes or fire fighting.

To verify the above assumptions, water levels in each individual LCVA of a MLCVA were set to be constant and free vibration experiments of LCVAs 1, 4, and 5, as shown in Figure 4, were conducted. Then a hole was drilled at both ends of each horizontal column to connect each of LCVA together and free vibration experiments were repeated. The results from both free vibration experiments are presented in Figure 5. The faster decay signals of liquid movement from the connected LCVA can be seen in Figure 5.

LCVA liquid damping ratios of both experiments were analyzed and presented in Figure 6. The higher LCVA liquid damping ratios were obtained after the connecting holes were drilled in the horizontal columns. This is probably due to the additional energy dissipation associated with the presence of the connecting holes.

LCVA natural frequencies measured before and after drilling connecting holes are presented in Figure 7 with respect to $h_v/d$ . From Figure 7 it can be seen that drilling connecting holes had a negligible effect on LCVA natural frequency. The natural frequencies of both LCVA configurations show good agreement with natural frequencies predicted by Equations (1) and (2), using appropriate $\alpha_{\rho\eta}$ values.

## 3. CONCLUSIONS AND FUTURE STUDIES

The following conclusions can be made from the results:

1. $\alpha_{\rho\eta}$ is dependent on the ratio of vertical column height to horizontal column length.
2. The natural frequencies of each LCVA in a MLCVA did not change after connecting holes were drilled in horizontal columns.
3. A more practical MLCVA configuration may have constant liquid levels in each individual LCVA.
4. Liquid damping ratios of each individual LCVA in a MLCVA were increased by drilling holes.

In future research, other geometric parameters of bi-directional LCVAs and MLCVAs will be studied. Experiments to study interaction between vibration absorbers and a pendulum structure under random load will be undertaken.

## 4. REFERENCES


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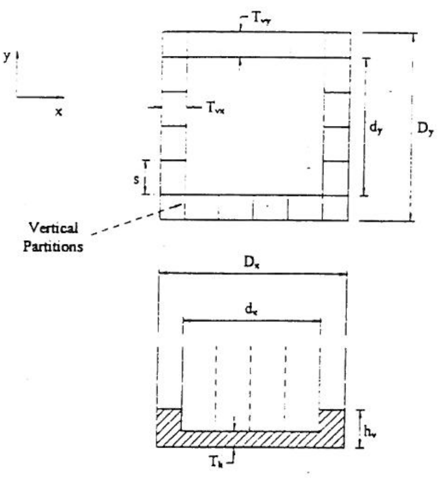


Figure 1 Bi-directional LCVA, Hitchcock et al. (1997).

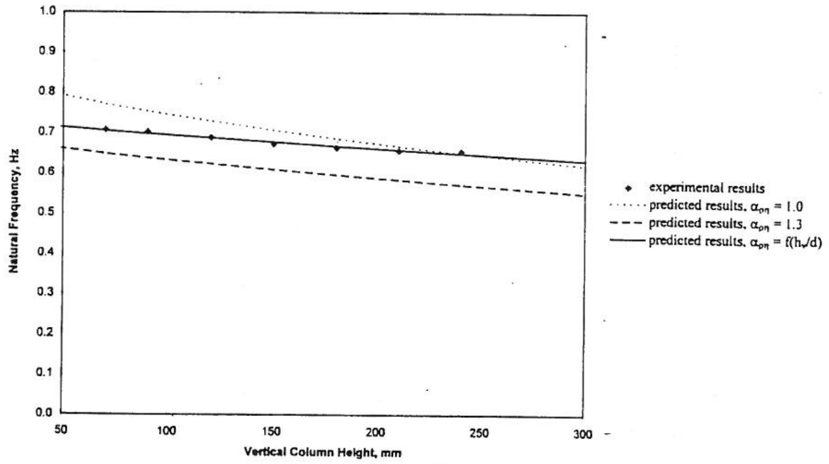


Figure 2 Comparison of Experimental and Calculated LCVA Natural Frequencies.

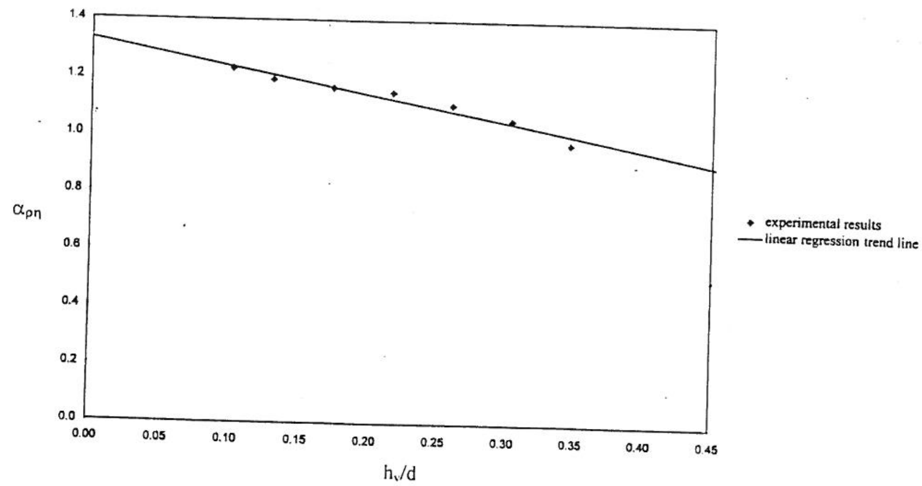


Figure 3 Variation of $\alpha_{\rho\eta}$ with respect to $h_v$/d.

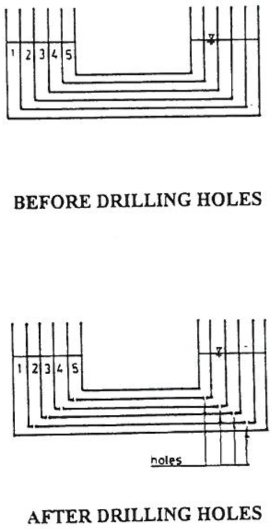


Figure 4 MLCVA Before and After Drilling Connecting Holes.

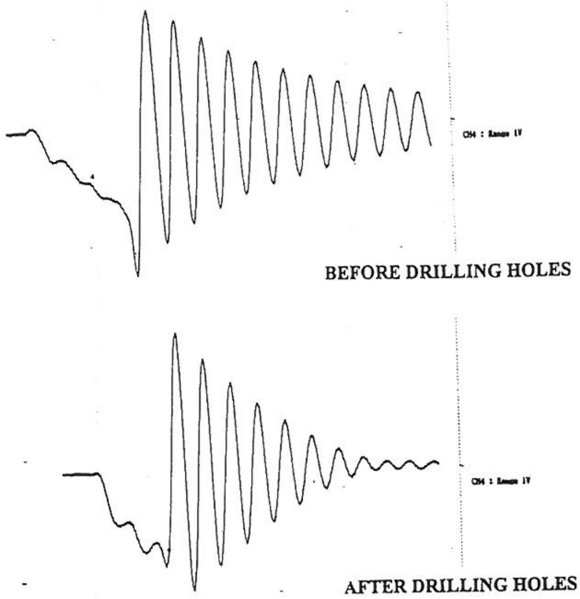


Figure 5 Decay Signal of Free Vibration Experiments Before and After Drilling Connecting Holes

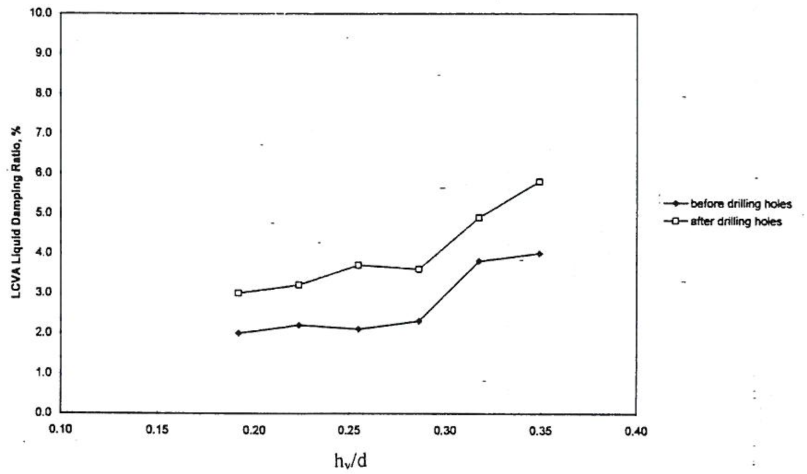


Figure 6 Comparison of LCVA Liquid Damping Ratios Before and After Drilling Connecting Holes.

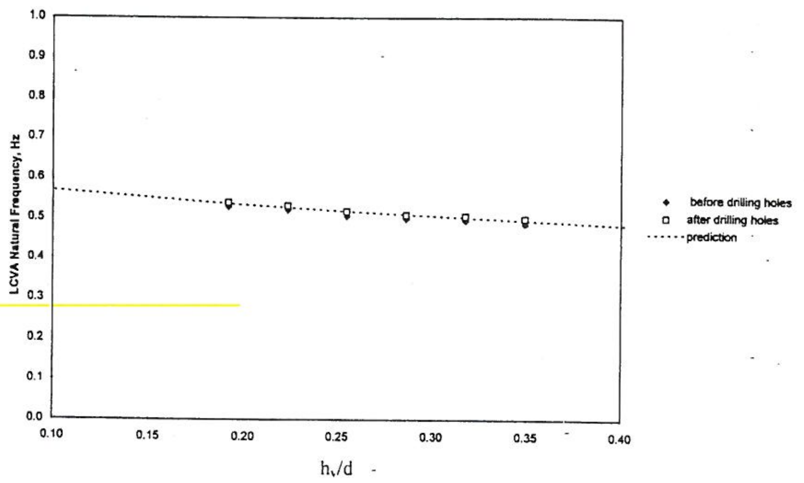


Figure 7 Variation of LCVA Natural Frequencies with respect to $h_v/d$.