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A Review on Tuned Liquid Column Dampers (TLCDs) and Tuned Liquid Column Dampers with Embossments (ETLCDs)

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Abstract – *Development of high-strength materials and construction technologies has led to longer- spanning and taller buildings. Hence, control of vibrations induced in structures by lateral loads, such as wind and earthquakes, is an important consideration in the design of high-rise buildings. Typical methods to improve structural safety and serviceability of these high-rise buildings involve installing additional vibration suppression devices in them. Tuned Liquid Column Damper (TLCD) uses the sloshing of a liquid as the control force. It is a type of passive damper. Most extant studies in TLCD focus on improving its damping force by use of pressure losses by orifice, valve or high-viscosity liquids. This study focuses on reviewing two recent modifications in TLCDs, i.e., Tuned Liquid Column Damper with Embossments (ETLCD) and Liquid Column Vibration Absorber (LCVA). The study also aims at analyzing the performance of these two types of dampers in earthquake response reduction compared to the conventional TLCD.*

***Key Words*: Vibration suppression devices, Tuned Liquid Column Damper (TLCD), Passive dampers, valve-type damper, Tuned Liquid Column Damper with Embossments (ETLCD), Liquid Column Vibration Absorber (LCVA).**

1. INTRODUCTION

Control system approaches for vibration mitigation in structures can be classified into passive control, semi-active control, active control, and hybrid control strategies. Semi-active, active and hybrid control devices (a combination of the semi-active and active) rely on a control algorithm, where either a variable damper property or a variable control force is adjusted, based on the identification of the structural vibration behaviour. Passive systems cannot adjust to the varying structural and excitation parameters. However, passive control devices are still the primary choice in engineering applications. They are more robust since they do not rely on additional external energy supply. Also passive devices are usually cheaper in installation and maintenance. The different types of dampers and their energy dissipation methods are given in table 1. Table 2 gives the various application areas of the different types of dampers.

Table -1: Types of dampers and their energy dissipation methods

Types of Dampers	Mode of energy dissipation
Friction Dampers	Energy is absorbed due to friction between the surfaces rubbing against each other.
Viscous Dampers	Energy is absorbed by fluid passing between piston-cylinder arrangements.
Yielding Dampers	Energy is absorbed by providing metallic components that yield.
Magnetic Dampers	Energy is absorbed by magneto-rheological fluid.
Tuned Mass Dampers	It resists resonance frequency oscillations using springs, fluids or pendulums.

Table -2: Dampers and their applications

Types of Dampers	Applications
Friction Dampers	Bracing, Retrofitting of buildings.
Viscous Dampers	Automobiles, Bracing in buildings.
Yielding Dampers	To reduce the seismic response of inter-story drift.

1.1 TUNED LIQUID COLUMN DAMPERS

Tuned Liquid Dampers (TLDs) are passive damping systems in which, water is confined in a container and uses the sloshing energy of water to reduce the dynamic response of the structure during excitation. TLDs are highly effective in absorbing the low-frequency vibrations. A special case of TLD, Tuned Liquid Column Dampers (TLCDs) having U-shaped tube containing liquid (usually water) as shown in figure 1 is found to reduce structural vibrations considerably through the motion of the liquid residing in the container. The motion of liquid inside the column counteracts the action of the external excitations. The damping effect of TLCD is due to the head loss of hydraulic pressure of the liquid due to the orifice installed inside of the container, and the viscous action in the boundary layers. The damper is economical and flexible since it can be easily tuned to the primary structure by changing the length of the liquid column.

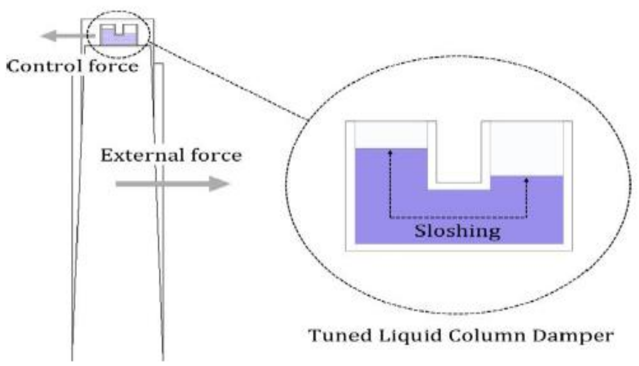

Fig -1: Tuned Liquid Column Damper (B. Park et al., 2018)

2 LITERATURE REVIEW

Park (2018), proposed a damping mechanism using embossments on the wall of the TLCD (termed as ETLCD). In this study, experimental evaluation of the vibration control performance of tall buildings with ETLCD is carried out and the results indicated that, vibration control performance of ETLCD is superior to that of the conventional TLCD.

Mishra and **Pandey (2018)**, studied about Circular Liquid Column Ball Dampers (CLCBDs) in reducing torsionally coupled vibrations of buildings subjected to wind excitations. CLCBDs are equipped with moving orifice, implemented via steel balls, placed at the middle of the liquid tube. An experimental program had been taken up to verify the performance of the CLCBD system by simulating narrow band lateral excitation, typical to wind. The study concludes that the efficiency of CLCBD is more than a conventional TLCD.

Dziedziech *et al.* (2018), focused on open and sealed TLCD, and conducted experimental tests on a full scale model of the damper excited by means of a hydraulic shaker. Displacement of the liquid column was measured and the results indicated that damping ratio is nonlinear, time-varying and depends on the level of vibration.

Furtmüller *et al.* (2018) studied a TLCD installed at the base to reduce the dynamic displacement demands of the base-isolation subsystem. Outcome of this experimental investigation concludes that the proposed hybrid control strategy reduces the displacement demand of the base-isolation and also enhances the dynamic performance of the complete structural system.

Altay *et al.* (2017), proposed a Semi-Active Tuned Liquid Column Damper (S-TLCD), which tune both the natural frequency and the damping ratio by adapting its parameters to the changing loading and structural conditions. The S-TLCD showed a higher performance regardless of the fluctuations in natural frequency of the building.

3. LIQUID COLUMN VIBRATION ABSORBER (LCVA)

A particular type of TLCD is called Liquid Column Vibration Absorber (LCVA), whose horizontal cross-sectional area is different than that of the vertical section. A typical LCVA is shown in figure 2. LCVAs possess several advantages when compared to other passive vibration control devices because of their lower cost, easy installation in existing structures, easier handling and few maintenance requirements. In most of these dampers water is used as the liquid which may also be used for water supply and as well as for fire fighting.

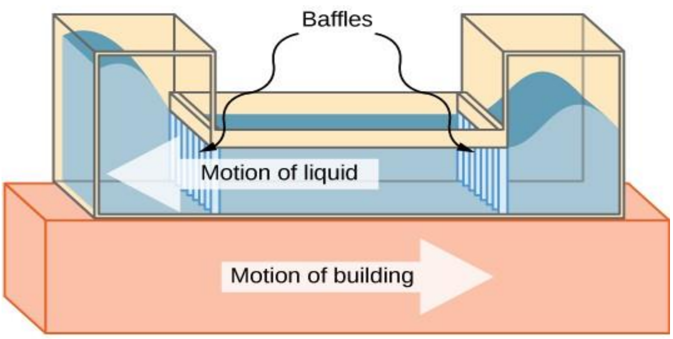

Fig -2: Liquid Column Vibration Absorber

3.1 Dynamic response control of structures using LCVA

To analyse the efficiency of LCVA in mitigating the response of the structure subjected to sinusoidal external motion, the arrangement of the steel structure model over the shake table along with the LCVA model as shown in figure 3 is used by Parka et.al. The shake table, which is unidirectional in nature, will impose horizontal motion to the structure. [2]

Fig -3: LCVA structure experimental setup

In each set of the experiments, the damper-structure system, have been subjected to harmonic sinusoidal base motions and displacement and acceleration responses collected.

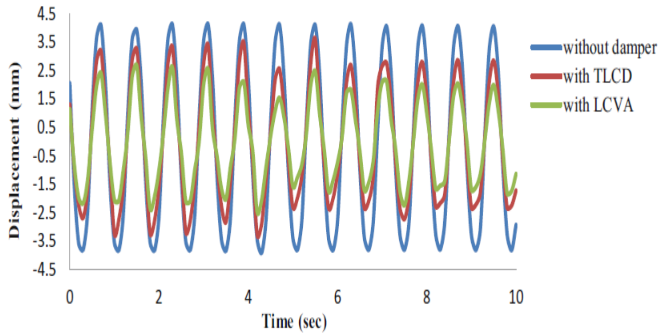

Fig -6: Variation of displacement of structure with time (with and without damper) for mass ratio 5%, excitation frequency ratio 1, tuning ratio 1 and length ratio 0.7[2]

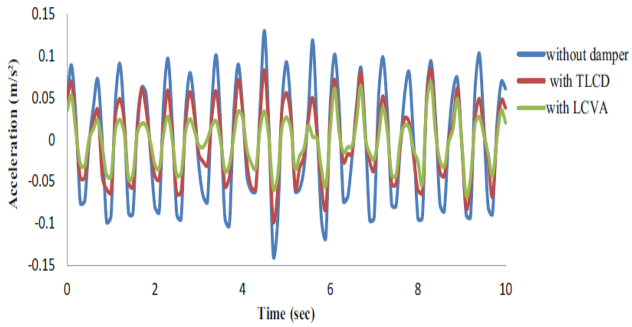

Fig -7: Variation of acceleration of structure with time (with and without damper) for mass ratio 5%, excitation frequency ratio 1, tuning ratio 1 and length ratio 0.7[2]

The effectiveness of the TLCD was found to be 41.066% and 41.509% in reducing the displacement and acceleration of the structure system, whereas for the LCVA those responses reduced up to 55.709% and 52.439%, respectively, at the tuned condition as well as at the resonance region [2]. Results of this experiment show that LCVA and TLCD both can successfully mitigate the response of the structure. Also, LCVA has better efficiency in reducing the responses than TLCD.

4. TUNED LIQUID COLUMN DAMPERS WITH EMBOSSMENTS (ETLCDs)

Tuned Liquid Column Dampers with Embossments (ETLCD) is a type of modified TLCD developed to improve its damping properties and overall efficiency. In ETLCD, embossments or projections are provided on the inner surfaces of the horizontal and vertical tubes. These embossments increase the roughness of the inner surfaces and hence the damping property is improved.

4.1 Dynamic response control of structures using ETLCDs

In order to investigate the effects of embossments, a tank with embossments and a tank without embossments were fabricated and studied by Saha and Debbarma. The figure below shows the tank dimensions and layout.

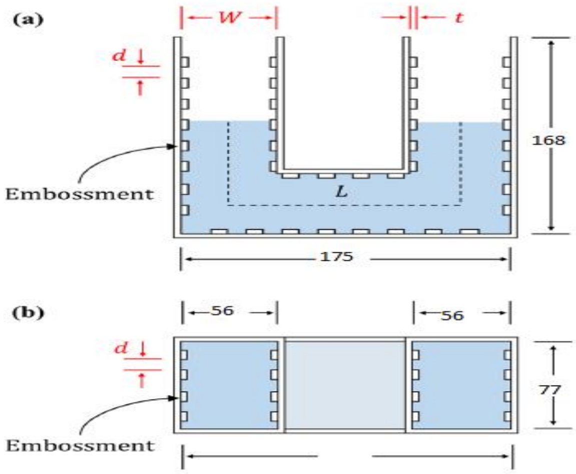

Fig -8: Dimension of an ETLCD specimen for characteristic experiment (a) elevation; (b) plan (dimensions: mm) [8]

The vibration control experiment consisted of a free vibration test and a forced vibration test by using a harmonic load. The experimental setup is shown in figure 9.

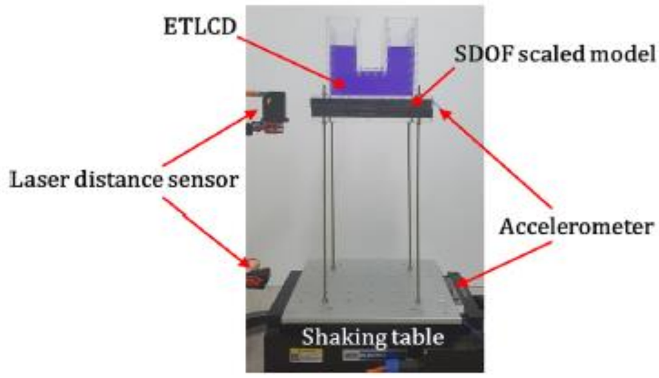

Fig -9: Experimental setup for vibration control experiment [8]

In free vibration test as shown in figure 10, the tendency of damping with ETLCD was 2.6 to 17.8%. Thereby indicating a 2.7 times higher performance to ETLCD than TLCD.

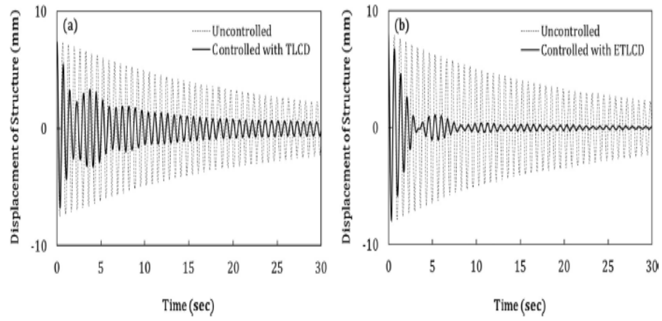

Fig -10: Time history curve of the free vibration test: (a) structure with TLCD; (b) structure with ETLCD [8]

In forced vibration test as shown in figure 11, the maximum response acceleration with ETLCD decreased by 50.4% which demonstrates that the vibration control performance of ETLCD was 1.2 times that of TLCD.

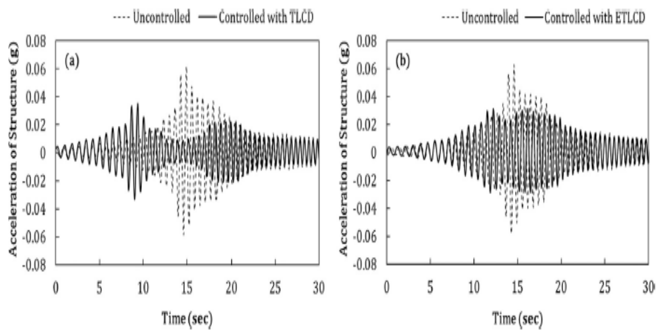

Fig -11: Time history curve of the forced vibration test: (a) structure with TLCD; (b) structure with ETLCD [8]

5. CONCLUSIONS

The study on Tuned Liquid Column Dampers (TLCDs) aimed at knowing the mechanism behind the damping nature of them and also to study the effect of the two types of modified TLCDs in dynamic response.

Liquid Column Vibration Absorbers are special types of TLCDs in which the cross-sectional area of horizontal tube is different from that of vertical tube, unlike in the case of TLCDs. From the review, it has been found that LCVA can successfully mitigate the response of the structure more efficiently than TLCD.

Tuned Liquid Column Dampers with Embossments (ETLCD) are also special types of TLCDs in which the inner surfaces are provided with embossments. It was observed from the study that ETLCD exhibits more efficient control performance than the conventional TLCD.

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