Development of a scaled rectangular tuned liquid damper to study experimentally wind-induced response mitigation

Rigoberto Nava-González [1], Adrián Pozos-Estrada [1], Adrián López-Ibarra [1] and Miguel A. Hernández-Martínez[1]

[1]*National Autonomous University of Mexico, Mexico City, Mexico, RNavaG@iingen.unam.mx, APozosE@iingen.unam.mx, ALopezI @iingen.unam.mx,* MHernandezMa@iingen.unam.mx

SUMMARY

The use of energy dissipation devices to mitigate wind-induced vibration in tall buildings is very popular worldwide. A type of passive energy dissipation device is the tuned liquid damper (TLD), which has been very well studied by several authors and different methodologies have been developed to calculate the parameters (mass, frequency and damping) to characterize it. In this work, a description of the setup and experimental tests of a rectangular TLD with damping screens subjected to sinusoidal excitation is reported. For the experimental study, the scaled rectangular TLD was excited with different sinusoidal signals and high-speed videos were recorded to study the water level during the motion. A processing of the high-speed video images is carried out to estimate time histories of the water level at predefined points. A postprocessing of the high-speed video images, which is currently in progress, will be used to identify the frequency and damping that characterizes the TLD.

Keywords: Tuned Liquid Damper, Damping, Modal Frequency, High-Speed Video

1. INTRODUCTION

Due to the use of lightweight materials and more complex geometries in tall buildings, wind-induced vibration can be of concern. An option to reduce excessive vibrations is the implementation of auxiliary damping systems, which have presented favourable results for vibration control (Soong and Dargush, 1997). Passive vibration control systems have been widely applied to control wind-induced responses (Pozos-Estrada and Hong, 2015; Pozos-Estrada and Gómez, 2019). One of the most popular damping devices is the Tuned Liquid Damper (TLD), which presents easy tuning with the dynamic properties of the main structure, low cost and minimal maintenance (Soong and Spencer, 2002; Love and Tait, 2015).

The TLD consists of a tank partially filled with water (Newtonian fluid), which is tuned to one or more fundamental modes, which will have the greatest participation in the structural response. The damping is induced by the formation of surface waves in the liquid and their interaction with the walls of the system that contains it, likewise, if necessary, to increase the inherent damping of the secondary system, flow dissipating devices such as nets can be installed, screens, deflectors or vanes (Tait et al., 2005; Ruiz and Lopez-García, 2013).

Based on the linear wave theory, the natural the frequency of the *nth* sloshing mode can be obtained as (Ibrahim, 2005):

$$f_{TLD} = \sqrt{\frac{n\pi g}{L}\tanh\left(\frac{n\pi h}{L}\right)} \quad (1)$$

where L is the length of tank in meters, h is the height of water in the rectangular tank in meters and g is the acceleration of gravity equal to 9.81 m/s^2.

Several researchers have presented equations to estimate the damping associated with TLD devices with dissipative screens, in the present investigation it is assumed that for sinusoidal excitation Eq. 2 can be used to determinate the amplitude-dependent damping ratio (Tait,2008):

$$\zeta_{eq} = C_I \frac{16}{3\pi^2}\tanh^2\left(\frac{\pi h}{L}\right)\Delta\Xi \frac{x_r}{L} \quad (2)$$

Eqs. (1) and (2) were used to build the scaled tuned liquid damper with screens.

2. EXPERIMENTAL SETUP

The scaled TLD model was made of a 0.95 cm thick acrylic plate. Its length, width, and height are equal to 100 x 100 x 50 cm. A steel structure was built to connect the scaled TLD and a MTS 244 dynamic actuator. Fig. 1 shows the complete setup which included the tank, the steel structure, a MTS 244 dynamic actuator to be able to replicate sinusoidal signals with a frequency of 0.62 Hz and different amplitudes, two S-load cells and two wireless accelerometers.

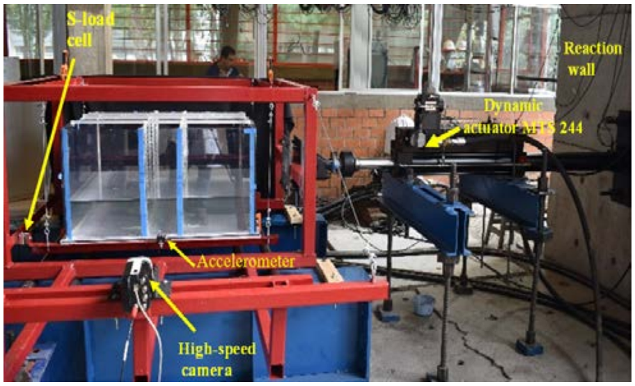

Figure 1 Experimental test setup

For the calibration of the dynamic actuator, "Tuning" tests were carried out, which consists of matching the input signals, either the sinusoidal or random signals, with the output signal of the MTS Flextest system to the MTS 244.22 10 t actuator. Figure 2 presents a comparison of the actuator command signal vs actuator motion signal. It can be observed from Figure 2 that the signal has a 10 s delay with respect to the start of the input signal, since a ramp with zero displacement of 10 s was added to have a better control of the measured data. Likewise, it is observed that the signals practically overlap and the percentage error of the displacement measured with the displacement sensor (LVDT) was about 0.02%.

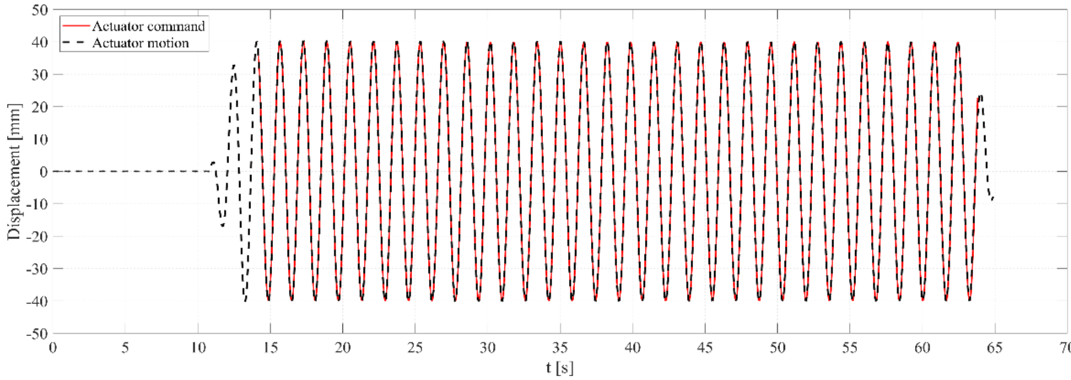

Figure 2 Comparison of the actuator command and its motion

3. ANALYSIS PROCEDURE

Several experimental tests were carried to evaluate the dynamic properties of the scaled TLD. For the experimental tests, sinusoidal signals with different frequencies and amplitudes were considered. During the experiments, a high-speed camera was used to record during the tests at a rate of 500 pictograms per second, a total of 28.96 s, a secondary lighting system was used to improve the light of the videos. It is noted that the use of high-speed videos to evaluate the properties of a device results in a viable tool. For example, Gardarsson (1997) used laser imaging to measure the sloshing behaviour of a water tank using shaking table tests, Lobovský et al., (2014) carried out investigations of the behaviour of dynamic pressures during dam failure using a high-speed video camera. More recently Min et al., (2016) developed a fast vision detection system based on the binary pixel count of the image portion in a pseudo-dynamic test of a Tuned Liquid Column Damper (TLCD).

The postprocessing of the high-speed video images with the program Tracker, which is a free video modelling and analysis tool built with Java (Open-Source Physics), this package is based on the recognition of points in 2D space, by associating a mass or control node to be able to monitor it so that it is possible to obtain histories over time of displacements, speeds or accelerations (Brown, 2005). Figure 3 shows that the point on interest can be tracked in an XY plane, in the right-hand side of the figure the time history responses for the 2 components are observed.

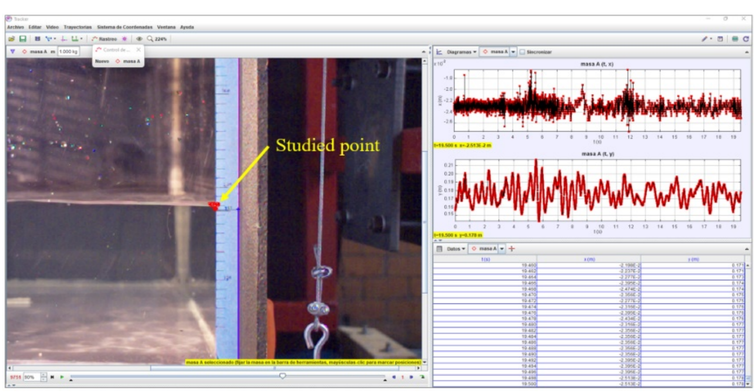

Figure 3 Tracker Software interface

4. RESULTS

The dynamic properties of the TLD-system can be easily obtained by determining the excitation frequency which corresponds to the peak value of the maximum water wave height at the end walls. For the 1.00 m-long tank, the experimental frequencies of the water sloshing were extracted by using the fast Fourier transform (FFT). Figure 4 shows the history in time of wave heights and the FFT of it, it can be seen that the response contains high frequency components, which for the particular case of the test are associated with noise and the frequency of dynamic actuator drive.

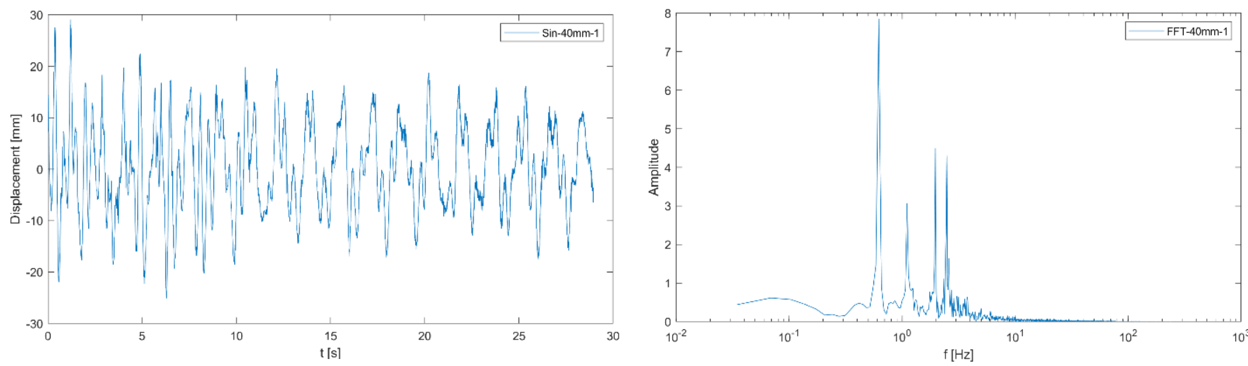

Figure 4 Time history of wave height and Fast Fourier Transform

Figure 5 shows a schematic diagram for the damping estimation procedure in the test. A sinusoidal signal with frequency ratio equal to unity (0.62 Hz) is applied for a limited time until a displacement response reaches the desired amplitude (40 mm), completing a total of 34 cycles, the dynamic actuator is set back to zero so that the TLD system undergoes in free vibration. A filtering of the signals was carried out.

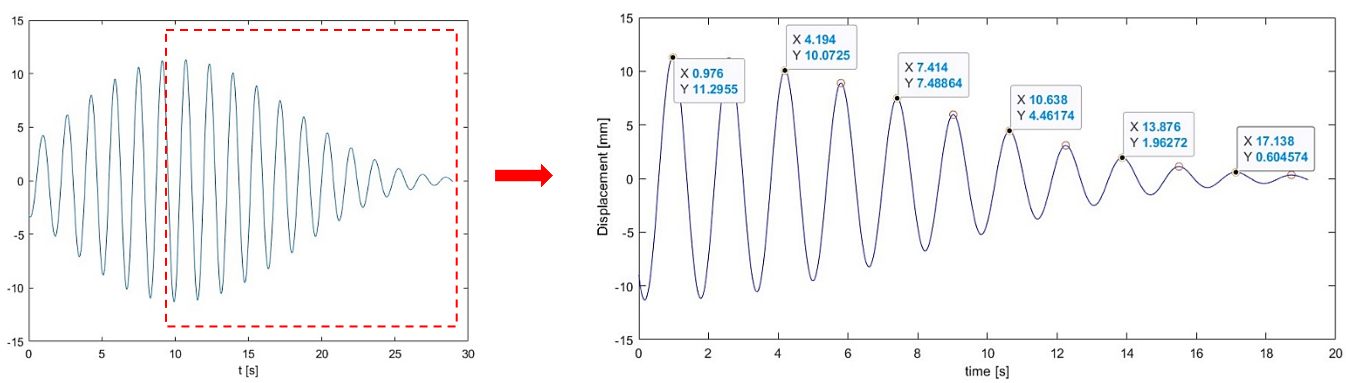

Figure 5 Free decay curve

Table 1 shows the values obtained for frequency and damping for the 5 tests of the TLD system subjected to a demand of amplitude equal to 40 mm, performing an average for each case, an average frequency of 0.62 Hz and a damping value of 5.1 % were obtained, it is worth mentioning that during the design of the test it was estimated that the damping of the TLD device was equal to 5.2%, presenting an error of less than 2%.

Table 1 Dynamic properties of TLD.

Test	ζ_{exp} [%]	Frequency [Hz]
Sin-40mm-01	5.06	0.6195
Sin-40mm-02	4.97	0.6171
Sin-40mm-03	5.17	0.6190
Sin-40mm-04	4.97	0.6194
Sin-40mm-05	5.72	0.6210

CONCLUDING REMARKS

A scaled TLD was constructed to experimentally study wind-induced response mitigation. The experiment considered a sinusoidal signal with a frequency and amplitude of 0.62 Hz and 40 mm. The work presents the evaluation of the dynamic properties of the TLD with the use of high-speed video images, which is a valuable tool for the characterization of this kind of systems, through the proposed procedure to evaluate the dynamical properties of TLD, it was observed the frequency and damping were closed to the target values, which confirms the validation of TLD design.

ACKNOWLEDGEMENTS

This work was supported by UNAM-PAPIIT IN103422.

REFERENCES

Brown, D., 2005. Tracker Sofftware, Video Analysis and Modelling Tool, Open Source Physiscs.

Gandarson, M., 1997. Shallow-water sloshing, PhD Thesis. University of Washington.

Ibrahim, R., 2005. Liquid Sloshing dynamics: Theory and applications. Cambridge, United Kingdom: Cambridge University Press.

Lobovský, L., Botia-Vera, E., Castellana, F., Mas-Soler, J., Souto-Iglesias, A., 2017. Experimental investigation of dynamic loads during dam break. Journal of Fluids and Structures, Vol. 48, 407-434.

Love, J. and Tait, M., 2015. Multiple Tuned Liquid dampers for efficient and robust structural control. Journal Structural Engineering, 141 (12): 04015045.

Min, K.W., Jang, S.J., and Kim, J., 2016. A Standalone Vision Sensing System for Pseudodynamic Testing of Tuned Liquid Column Dampers. Journal of Sensors, Vol. 2016, 11 pages.

Pozos-Estrada, A., and Gómez, R., 2019. Parametric study of the use and optimization of tuned mass dampers to control the wind and seismic induced responses of a slender monument. The Structural Design of Tall and Special Buildings.

Pozos-Estrada, A., and Hong, H., 2015. Sensitivity analysis of the effectiveness of tuned mass dampers to reduce the wind-induced torsional responses. Latin American Journal of Solids and Structures.

Ruiz, R., and Lopez-Garcia, D., 2016. Modeling and experimental validation of a new type of tuned liquid damper. Acta Mech , 3275-3294.

Soong, T., & Dargush, G., 1997. Passive energy dissipation systems in structural engineering. New York: Wiley.

Soong, T., and Spencer, B., 2002. Supplemental energy dissipation: state-of-the-art and state-of-the-practice. Engineering Structures, Vol. 24, 243-259.

Tait, M., El Damatty, A., Isyumov, N., and Saddique, M., 2005. Numerical Flow models to simulate tuned liquid dampers (TLD) with slat screens. Journal of Fluids and Structures, 1007-1023.

Tait, M., 2008. Modelling and preliminary design of a structure-TLD system. Engineering Structures, 2644-2655.