Modern Methods and Advances in Structural Engineering and Construction
Cheung, S. O., Yazdani, S., Ghafoori, N., and Singh, A. (eds.)
ISEC-6, Zürich, June 21–26, 2011

APPLICATION OF TUNED LIQUID DAMPER FOR CONTROLLING STRUCTURAL VIBRATION DUE TO EARTHQUAKE EXCITATIONS

BHARADWAJ NANDA[1] AND KISHORE CHANDRA BISWAL[2]

[1] Ex Post Graduate Student, Department of Civil Engineering, National Institute of Technology, Rourkela, Orissa, India
[2]Associate Professor, Department of Civil Engineering, National Institute of Technology, Rourkela, Orissa, India, Email: kcbiswal2003@yahoo.co.in

Current trends in construction industry demands for taller and lighter structures, which are also more flexible and having quite low damping value. This increases failure possibilities and also, problems from serviceability point of view. Several techniques are available today to minimize the vibration of the structure, out of which concept of using of Tuned Liquid Damper (TLD) is a newer one. The TLDs have been used to control the wind induced structural vibration. However, the seismic effective of TLD remain an important issue for the study. In this study, an attempt has been made to study the effectiveness of Tuned Liquid Damper (TLD) for controlling seismic vibration of the structure. Finite element elements are used to model the structure and the liquid in the TLD. A computer code is developed in MATLAB to study the response of the structure, the liquid sloshing in the TLD and coupled structure-TLD system. A ten storey and two bay frame structure was analyzed using different ground motions. First one was a sinusoidal loading corresponding to the resonance condition with the fundamental frequency of the structure, second one was corresponding to compatible time history as per response spectra of Indian Standard-1893 (Part -1):2002 for 5% damping at rocky soil. It is observed from the present study that, TLD can be used to control the vibration of the structure due earthquake excitations. Only Tuned Liquid Dampers, which are properly tuned to natural frequency of structure, are more effective in controlling the vibration. The damping effect of TLD decreases with mistuning of the TLD.

Keywords: Tuned Liquid Damper, Sloshing, Finite Element Analysis, Galerkin weighted residual method, Earthquake Excitations, tuned frequency.

1 Introduction

Now-a-days there is an increasing trends to construct tall structures, to minimize the increasing space problems in urban areas. These structures are often made relatively light & comparatively flexible, possessing quite low damping, thus making the structure more vibration prone. Besides increasing various failure possibilities, it may damage cladding and partitions and can cause problems from service point of view. Therefore, to ensure functional performance of tall buildings, it is important to keep the frequency of objectionable motion level below threshold. Various possibilities are available to achieve this goal [Kareem and Kijewski–Correa (1999), Spencer and Sain (1997)]. Along with some unique advantages, all of these techniques have some of their own restrictions & disadvantages. However, the use of Tuned Liquid Dampers (TLDs), comprising both Tuned Sloshing Dampers (TSDs) and Tuned Liquid Column Damper (TLCDs), are gaining wide acceptance as a suitable method of structural control. Since 1950s dampers utilizing liquid is being used in anti-rolling tanks for stabilizing marine vessels against rocking and rolling motions. In 1960s, the same concept is used in Nutation Dampers used to control wobbling motion of a satellite in space. However, the idea of applying TLDs to reduce structural vibration in civil engineering structures began in mid 1980s, by Bauer (1984), who proposed the use of a rectangular container completely filled with two immiscible liquids to reduce structural response to a dynamic loading. Modi & Welt (1988), Fujii et al. (1990), Kareem (1990), Sun et al. (1992), and Wakahara et al. (1992) were also among the first to suggest the use of dampers utilizing liquid motion for civil engineering structures. The principles of operation of all of these dampers were based on liquid sloshing, for which these are sometimes referred as Tuned Sloshing Damper (TSDs).

Several other types of liquid dampers are also proposed during last two decades, out of which Tuned Liquid Column Damper [Sakai et al. (1989), Xu et al. (1992)] which suppresses the wind induced motion by dissipating the energy through the motion of liquid mass in a tube like container fitted with orifice, is well known.

Tuned Sloshing Dampers (TSDs) are generally rectangular type or circular type and are installed at the highest floor according to building type . A TSD can be classified as shallow water type or deep water type depending on height of water in the tank. This classification of the TSDs is based on shallow water wave theory [Horikawa (1978)]. If the height of water 'h' against the length of the water tank in the direction of excitation 'L' (or diameter 'D' in case of circular tank) is less than 0.15 it can be classified as shallow water type else as deep water type if is more than 0.15. The depth of the liquid in a container can be deep or shallow, depending on the natural frequencies of the structure under control. Shallow water type has a large damping effect for a small scale of externally excited vibration, but it is very difficult to analyze the system for a large scale of externally excited vibration as sloshing of water in a tank exhibits nonlinear behavior. In case of deep water type, the sloshing exhibits linear behavior for a large scale of externally excited force [Kim et al. (2006)].

When frequency of tank motion is close to one of the natural frequencies of tank fluid, large sloshing amplitudes can be expected. If both frequencies are reasonably close to each other, resonances will occur. Generally tuning the fundamental sloshing frequency of the TLD to the structures natural frequency causes a large amount of sloshing and wave breaking at the resonant frequencies of the combined TLD-Structure system, this dissipate a significant amount of energy [Shang and Zhao (2008)].

2 Finite Element Formulation

The governing differential equation in terms of pressure variablein the TLD is

$$\nabla^2 P = 0 \qquad \text{on V} \qquad (1)$$

where, V is the volume of liquid domain

$P = P(x, z, t)$ is the liquid dynamic pressure,

and, $\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial z^2}$

Boundary Conditions:

(i) At liquid free surface

$$\frac{\partial^2 P}{\partial t^2} + g\frac{\partial P}{\partial n} = 0 \qquad \text{on } B_f$$

(ii) on rigid solid boundary

$$\frac{\partial P}{\partial n} = 0 \qquad \text{on Bs}$$

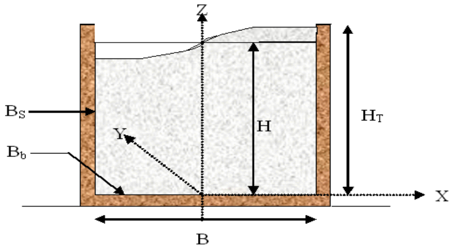


Figure 1. A Tuned liquid damper

Applying divergence theorem to the residual form of governing differential equation for the liquid and minimizing the energy function, one obtains:

$$\int_V \left(\frac{\partial N_i}{\partial x}\sum_1^N \frac{\partial N_j}{\partial x}\overline{P}_j + \frac{\partial N_i}{\partial z}\sum_1^N \frac{\partial N_j}{\partial z}\overline{P}_j\right) dV = \int_B N_i \frac{\partial P}{\partial n} ds$$

On substitution of boundary conditions and on simplifications, one gets

$$\lfloor M_f \rfloor \ \{\ddot{P}\} + \lfloor K_f \rfloor \ \{P\} = \{F_p\}$$

where $\lfloor M_f \rfloor$, $\lfloor K_f \rfloor$ and $\{F_p\}$ are liquid free surface matrix, liquid matrix and force vector, respectively.

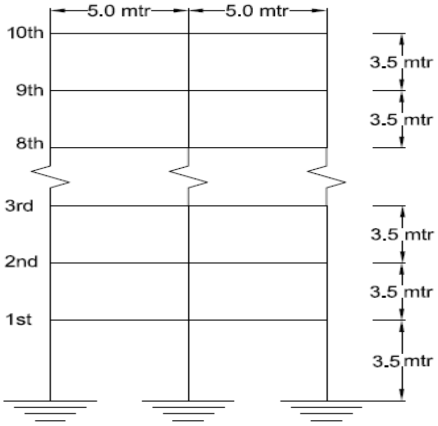
The dynamic equation of the structure-TLD interaction model is given below:

$$[M]\{\ddot{X}\} + [C]\{\dot{X}\} + [K]\{X\} = -[M]\{\ddot{X}_g\} + \{F_{TLD}\}$$

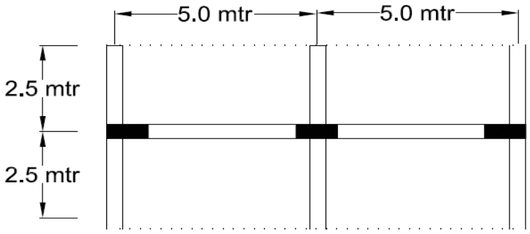
Where [M], [C] and [K] are mass, damping and stiffness matrices of the structural system. $\{\ddot{x}_g\}$ is ground acceleration. {FTLD} is resisting force to the structure at corresponding nodes due to TLD

3 Results and discussions:

A 10 storey framed structure has been considered for the analysis.



(A)



(B)

Figure2 (A) & (B) Elevation & plan showing the columns and beams at floor levels of the plane frame.

Assumed Preliminary data required for analysis of the frame:

a)	Type of the structure	Multi-storey rigid jointed plane frame.
b)	Number of stories	Ten, (G+9)
c)	Floor Heights & Bay widths	as shown in figure 2
e)	Imposed Load	3.5 kN/m^2
f)	Materials	Concrete (M25) & Steel (Fe 415)
g)	Size of columns	250mm x 450 mm
h)	Size of beams	250 mm x 400 mm in longitudinal direction
i)	Depth of slab	100 mm
j)	Specific weight of R.C.C.	25 kN/mm^3

Two types loading chosen are sinusoidal loading and the compatible time history as per spectra of IS-1893 (Part -1):2002 for 5% damping at rocky soil. (PGA = 1.0g) as shown in figure 3.

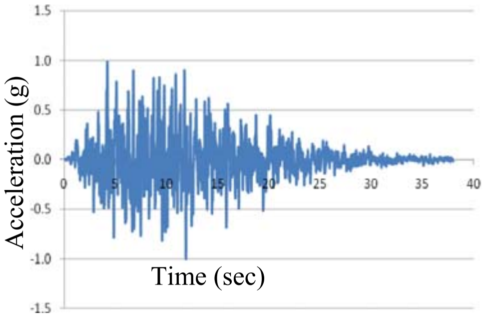


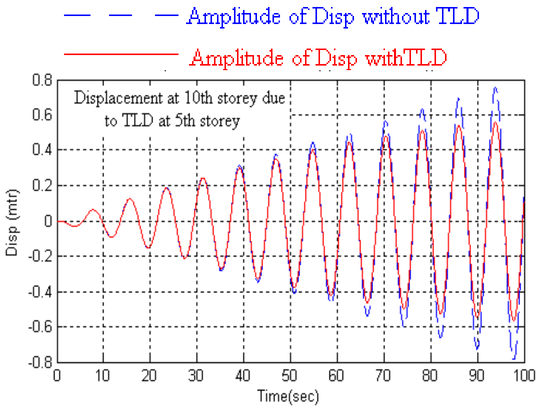
Figure 3 Compatible time history as per spectra of IS-1893 (Part -1):2002 for 5% damping at rocky soil

To study the effect of TLD on damping of the structure when they are placed at various floors, three cases are considered, by varying the position of TLD at 5th floor, 8th floor and 10th floor respectively. The structure is subjected to a sinusoidal forced horizontal base acceleration given by

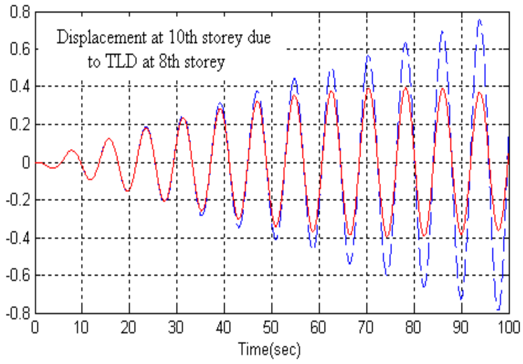
$$a_x(t) = X_0 \sin(\omega . t)$$

where X_0 and ω are taken as 0.1 m and 0.8032 rad/sec. The structure is discretized into 150 elements. The response of the structure at 10th storey is measured in terms of amplitude of displacement with TLD and displacement without TLD and presented in figures 4 (a,b & c).

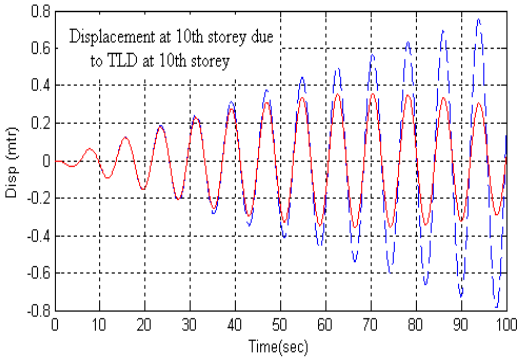
From the figures 4 (a,b & c) it has been found that the TLD is more effective, when it is placed at top storey.



(a) Displacement of 10th storey due to TLD at 5th storey

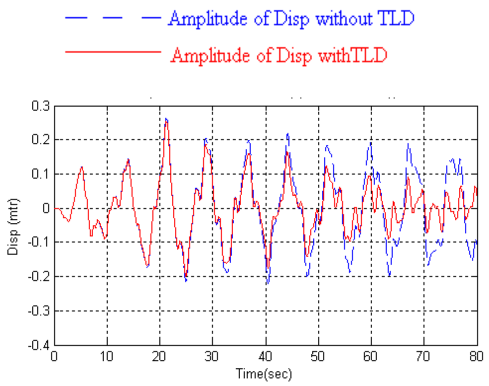


(b) Displacement of 10th storey due to TLD at 8th storey

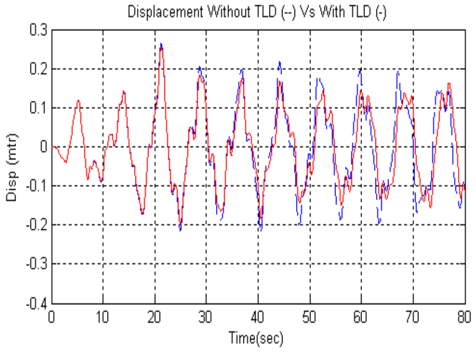


(c) Displacement of 10th storey due to TLD at 10th storey

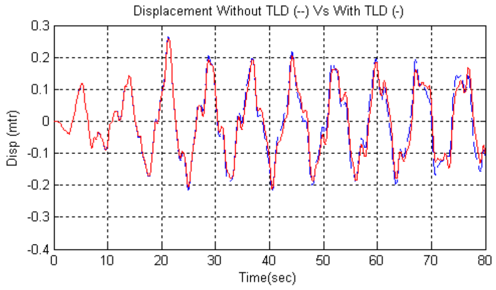
Figure 4 Displacement at top storey by placing TLD at various floors



a)TLD size is (10 m X 0.675 m)



b) TLD size is (9.5 m X 0.710 m)



c)TLD size is (9.5 m X 0.710 m)

Figure 5 Amplitude of vibration at top storey by placing TLD of different size, and when corresponding to compatible time history as per spectra of IS-1893 (Part -1):2002 for 5% damping at rocky soil, acting on the structure

4. Conclusion:

It is found that the TLD can be successfully used to control the seismic response of the structure. It is observed that TLD is more effective in reducing the dynamic response of the structure when placed at the top of the building. TLDs, which are properly tuned to natural frequency of structure. The damping effect of TLD is decreases with mistuning of the TLD.

References:

1. Kareem, A. and Kijewski–Correa, T., "Mitigation of motions of tall buildings with specific examples of recent applications." Wind and Structures, Vol. 2, No. 3, 201-251. 1999.

2. Spencer, B.F. Jr and Sain, Michael K., "Controlling Buildings: A New Frontier in Feedback." Special Issue of the IEEE Control Systems Magazine on Emerging Technology, Vol. 17, No. 6, 19-35. 1997.

3. Bauer, H.F., "Oscillations of immiscible liquids in a rectangular container: A new damper for excited structures." Journal of Sound and Vibration, 93(1), 117-133, 1984.

4. Modi, V.J., and Welt, F., "Damping of wind induced oscillations through liquid sloshing." Journal of Wind Engineering and Industrial Aerodynamics, 30, 85-94,1988.

5. Fujii, K., Tamura, Y., Sato, T. and Wakahara, T. "Wind-induced vibration of tower and practical applications of Tuned Sloshing Damper." Journal of Wind Engineering and Industrial Aerodynamics, 33, 263-272,1990.

6. Kareem, A. "Reduction of Wind Induced Motion Utilizing a Tuned Sloshing Damper."

Journal of Wind Engineering and Industrial Aerodynamics, 36, 725-737,1990.

7. Sun, L.M., Fujino, Y., Pacheco, B. M. and Chaiseri P., “Modeling of Tuned Liquid Damper (TLD).” Journal of Wind Engineering and Industrial Aerodynamics, 41-44, 1883-1894, 1992.

8.Wakahara T., Ohyama T., and Fujii K., “Suppression of Wind-Induced Vibration of a Tall Building using Tuned Liquid Damper.” Journal of Wind Engineering and Industrial Aerodynamics, 41-44, 1895-1906, 1992.

9.Sakai F., Takaeda S., and Tamaki T., “Tuned Liquid Column Damper – New type device for suppression of building vibrations,” Proc. Of International conference on High-rise Buildings, Vol. 2, Nanjing, China, 1989.

10. Xu X.L., Kwok K.C.S, and Samali B., “The effect of tuned mass dampers and liquid dampers on cross-wind response of tall/slender structures.” Journal of Wind Engineering and Industrial Aerodynamics, 40, 33-54, 1992.

11. Horikawa K., “Costal Engineering,” University of Tokyo Press, 5-118, 1978.

12. Kim Young-Moon, You Ki-Pyo, Cho Ji-Eun, and Hong Dong-Pyo, “The Vibration Performance Experiment of Tuned Liquid Damper and Tuned Liquid Column Damper.” Journal of Mechanical Science and Technology, Vol. 20, No. 6, 795-805, 2006.

13. Shang Chun-yu, and Zhao Jin-cheng, “Periods and Energy Dissipations of a Novel TLD Rectangular Tank with Angle-adjustable Baffles.” J. Shanghai Jiaotong Univ. (Sci.), 13(2), 139-141, 2008.