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RESEARCH ARTICLE OPEN ACCESS

Tuned Liquid Damper to Control Earthquake Response in a Multi-Storied Building Frame

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ABSTRACT
Damping is a phenomenon in which the energy of the system is gradually reduced and finally the vibration of the system is completely eliminated and the system is brought to rest. Several technologies are available to minimize the vibration of structures, of which, use of Tuned Liquid Damper (TLD) is a recent development. TLD is traditionally made of rigid tank filled with water. Once excited, the water inside the tank experiences sloshing motion as a result of building vibration and dissipates energy through the sloshing and wave-breaking of the liquid. This paper aims to study the effectiveness of TLD in reducing seismic vibration of a two-storied building frame when it is subjected to horizontal excitations. Analytical study of the undamped frame was carried out in ANSYS WORKBENCH software. Based on modes and frequencies obtained from analytical study, dimensions of steel building frame were fixed and experimental study was carried out by shake table experiments. Also various parameters that influence the effectiveness of TLD are studied.

***Keywords* -** Dampers, Horizontal excitation, Sloshing, Tuned Liquid Damper, Vibration Control

I. INTRODUCTION

In past few years, the increase in frequency of occurrence of natural disasters like earthquakes has been evident. Also due to urbanization and industrialization, demand for high-rise buildings has increased which are more flexible and have low damping value. As a result, sensitivity of these buildings to dynamic excitations has increased. Damping is one of the most important parameters that limit the response of the structures during such dynamic events. Tuned Liquid Damper (TLD) is a passive control device which has been installed in structures to suppress horizontal vibrations in the structures.

TLD is essentially a liquid filled tank which is rigidly connected to the top of the structure. It relies on the sloshing wave developing and breaking at the free surface of the liquid to dissipate a portion of the energy released during the dynamic event and therefore increases the equivalent damping of the structure. When frequency of tank motion is close to the frequency of the tank liquid resonance occurs. At resonance, large amount of sloshing and wave breaking occurs at the free surface of the liquid which dissipates a significant amount of energy. TLD presents several advantages over other damping systems such as low installation, running and operation cost, fewer mechanical problems since no moving parts are present and can be applied to control different vibration types of multi-degree of freedom systems.

The objectives of this paper is to reduce the structural response by installing a model of TLD attached to the structure subjected to horizontal excitations and to study the effects of various parameters which affect the structural response. The various parameters include damper liquid depth and mass of liquid the introduction of the paper should explain the nature of the problem, previous work, purpose, and the contribution of the paper. The contents of each section may be provided to understand easily about the paper.

II. FINITE ELEMENT ANALYSIS

The finite element modeling and analysis of the building frame model was performed using ANSYS WORKBENCH 2015. Modal analysis of the two storied building model was carried out to determine the natural frequencies and mode shapes. Structural steel was the material used to model the building in ANSYS. Table 2.1 shows the material properties considered during finite element analysis.

Table 2.1: **Material properties of structural Steel**

Material	**Density**	**Young's Modulus**	**Poisson's ratio**
Structural Steel	7850kg/m^3	2x10^{11} Pa	0.3

Beam and shell elements were used to model the frame. The element types used are IS BEAM 181, IS BEAM 188 and SHELL 181. Mesh connections are used to join the meshes of the topologically disconnected surface bodies. This mesh along with material properties is used to mathematically represent the stiffness and mass distributions of the structure. In ANSYS Workbench 2015, surface body is automatically meshed with shell element SHELL 181. Table 2.2 represents the geometrical properties of the building frame model.

Table 2.2 Geometric Properties of the Structural Model

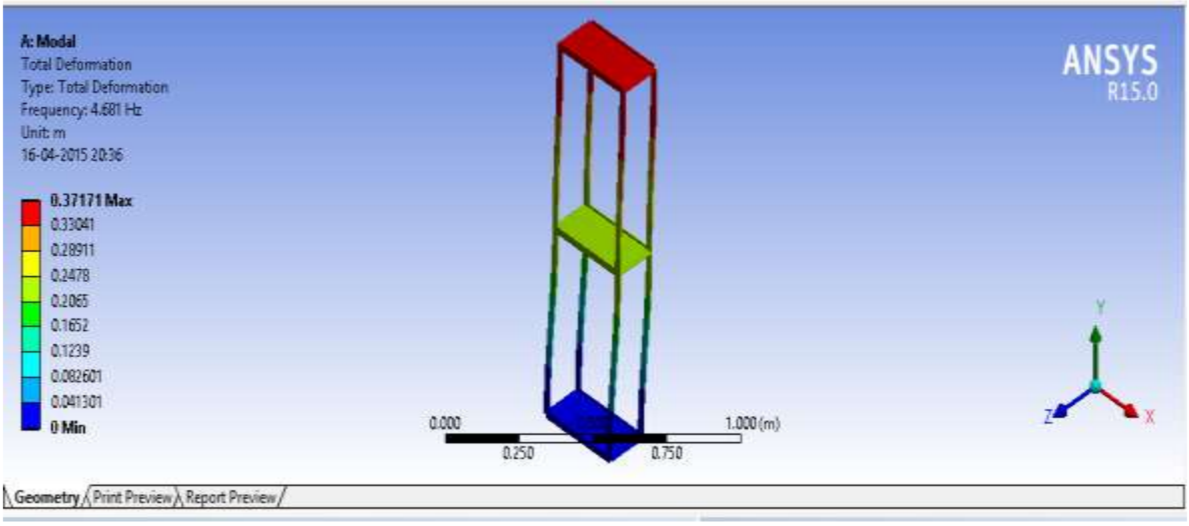
Sl.No	Parts	Dimensions in mm		
		Depth (D)	Width (B)	Length (L)
1.	Column	5	25	600
2.	Slab	8	150	300

Fixed support is applied at the base. The translational degrees of freedom in X and Y directions are fixed and free in Z direction and the rotational degrees of freedom in X, Y and Z directions are fixed. Modal analysis is conducted. Block Lanczos Mode Extraction method is used to solve and obtain the mode shapes and corresponding natural frequencies for the first 2 modes. (Table 2.3)

Table 2.3 Modal Analysis Results

Mode	Frequency(Hz)	Period(s)
1	4.681	0.2136
2	12.524	0.0798

The mode shapes obtained are shown in Fig. 2.1 and Fig. 2.2 (first and second modes).



A: Modal
Total Deformation
Type: Total Deformation
Frequency: 4.681 Hz
Unit: m
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Fig. 2.1 First Mode Shape

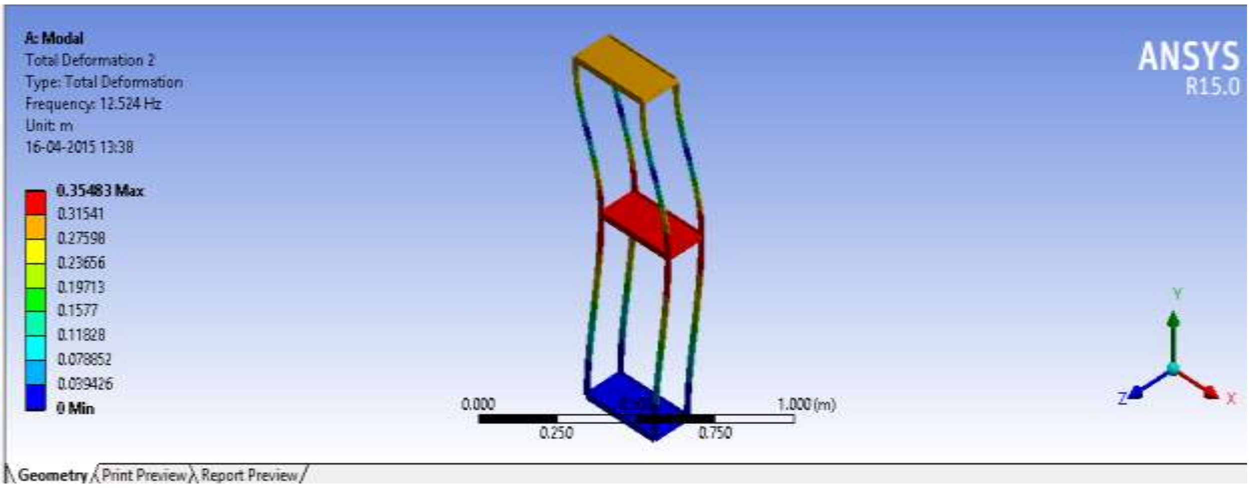

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Fig. 2.2 Second Mode Shape

III. EXPERIMENTAL SETUP

The experimental setup consists of a rectangular steel frame consisting three steel slabs attached to four rectangular steel columns at an interval of 600mm. The entire structure assembly is placed on a Horizontal Shake table driven by an electric motor. The operating frequencies of the shake table range from 0 to 25 Hz. The RPM of the motor can be varied to achieve harmonic base motions at different frequencies. Table 3.1 gives dimension of the structure.

Table 3.1 Geometric Data of the Structure

Sl.No	Parts	Dimensions in mm		
		Depth (D)	Width (B)	Length (L)
1.	Column	5	25	600
2.	Slab	8	150	300

The frame is designed to facilitate the visualization of the first two mode shapes. The model can be thought of as a model for a building frame with two floors which suffers earthquake like base motions. Fig. 3.1 represents the experimental setup of an undamped structure.

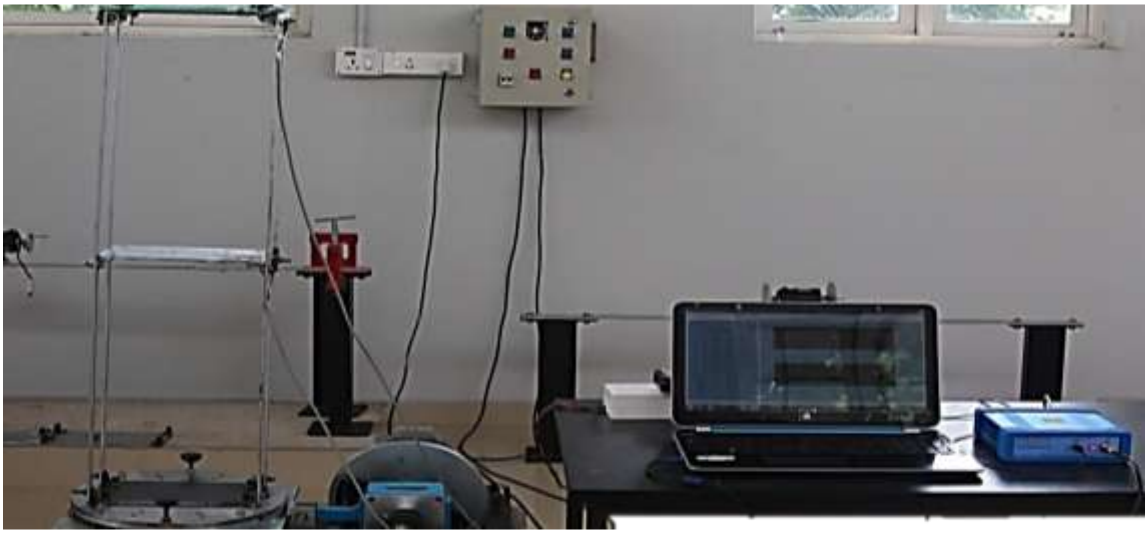


Fig. 3.1 Experimental Setup of Undamped Structural Model

IV. DAMPER STRUCTURE ARRANGEMENT

A glass container with shallow water is used as damper for the structure. The geometric property of the Liquid damper is shown in Table 4.1. The tank is placed at the top of the structure. Then the experiment is conducted with the two story frame placed on the shake table and the accelerometers have been connected to each floor i.e. first floor and second floor.

Table 4.1 Geometric Data of the Liquid Damper

Sl.No		**Dimensions in mm**		
	Depth (D)	**Width (B)**	**Length (L)**	**Thickness (t)**
1.	400	80	210	8

The accelerometer provides the displacement that occurs in the entire frame when the vibration of the shaker starts. Each accelerometer provides displacements at each floor. Fig. 4.1 represents the experimental setup of a building frame damped with Tuned Liquid Damper.

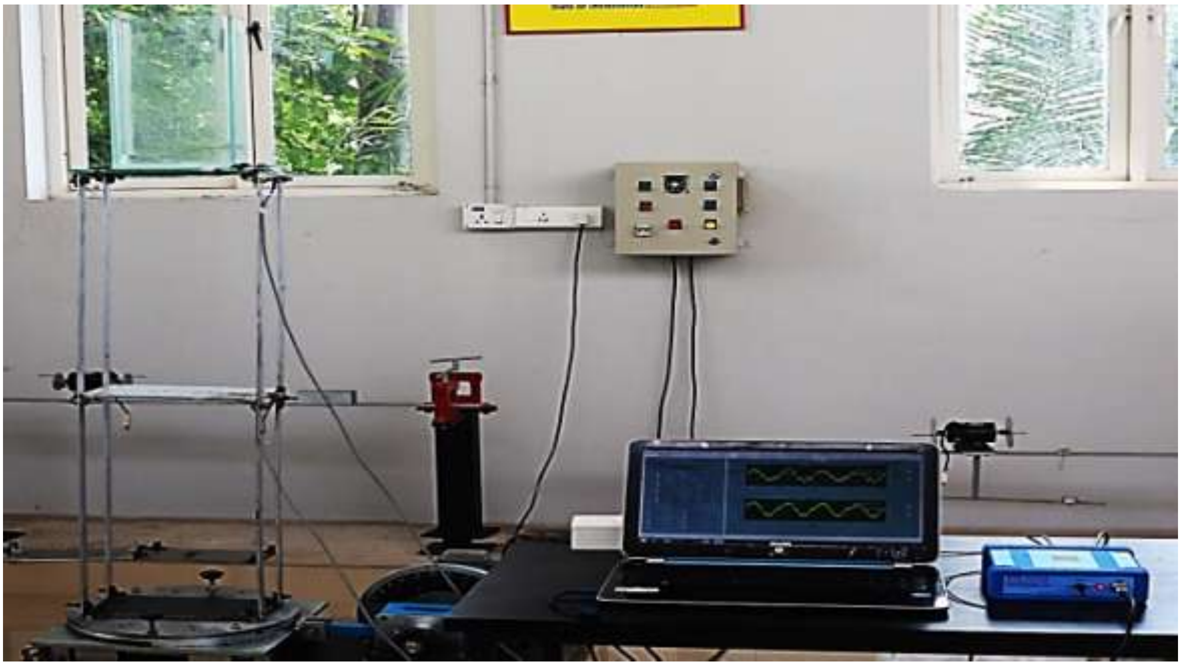


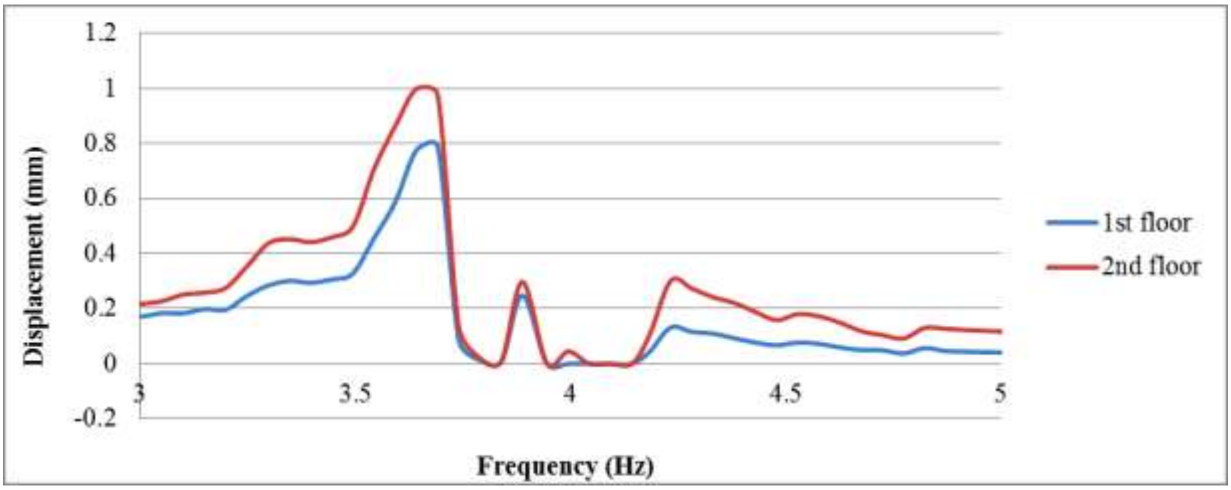
Fig. 4.1 Experimental Setup of the Structural Model Damped with TLD

V. RESULTS AND DISCUSSIONS

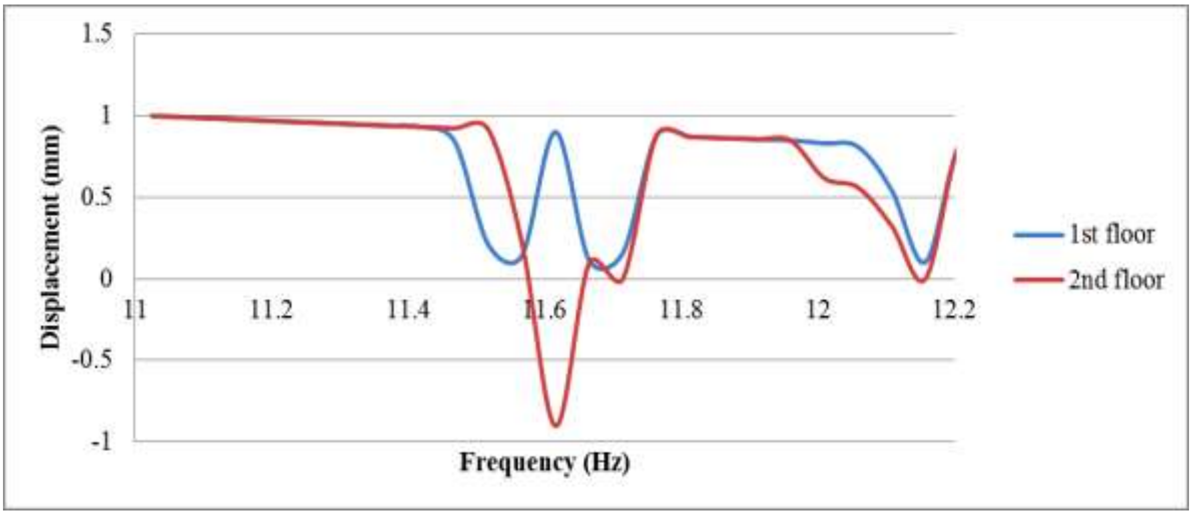
One of the primary objectives of the experimental study was to investigate the behaviour of water sloshing motion and the effects of the excitation frequencies, liquid depth and mass of liquid on the sloshing behaviour.

5.1 Effect of Seismic Excitation on an Undamped System

The displacement response of the undamped MDOF structure, when it is subjected to sinusoidal base excitation is measured from shake table experiment. First and second mode shapes are obtained from the experiment (Fig. 5.1 (a) and Fig. 5.1 (b)).



(a)



(b)

Fig. 5.1 Structural Response of the Undamped System showing (a) 1st Mode and (b) 2nd Mode

5.2 Comparison of Natural Frequencies

The displacement response of the undamped MDOF structure, when it is subjected to sinusoidal base excitation is determined from finite element modal analysis and also measured from experiment. Natural frequencies of the structural model and the finite element model are compared as shown in Table 5.1.

Table 5.1 Comparison of Natural Frequencies

Natural Frequencies (Hz)	Finite Element Model	Experimental model
1st Mode	4.681	3.691
2nd Mode	12.524	11.6156

From table 5.1 it can be concluded that natural frequency display good agreement between analytical and experimental results.

5.3 Comparison of Structural Response of Damped and Undamped Model

To understand the effect of damping, shake table experiments are conducted for both damped and undamped systems. From Fig. 5.2, we observe that there is an increase in effective damping of the combined system when the main system is coupled with the damper.

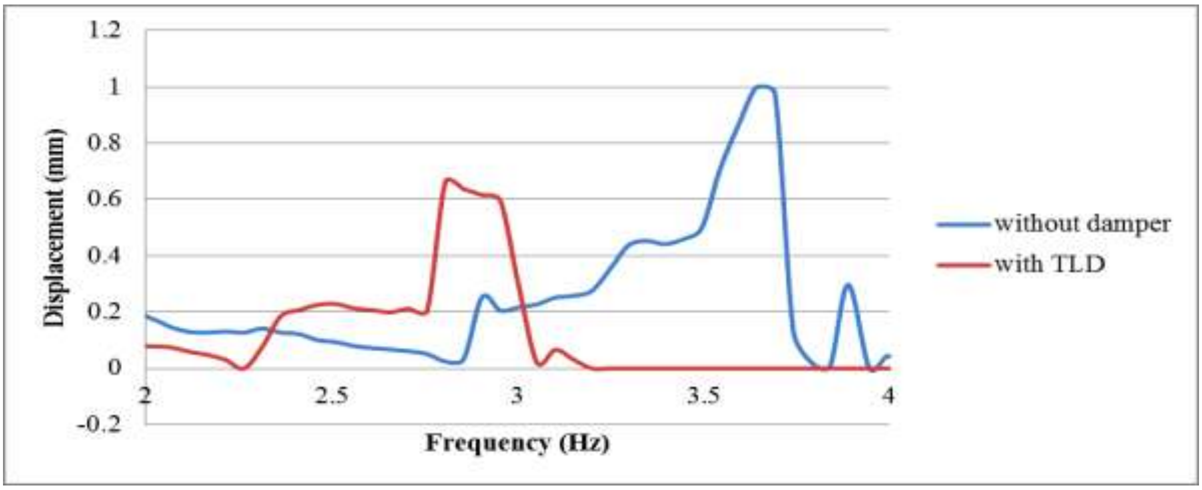


Fig. 5.2 Structural response of the Undamped System and the System Damped with TLD

5.4 Comparison of TLD Frequencies

In order to check the effect of liquid depth on damping, depth of liquid inside the dampers was varied and frequency was measured experimentally and compared with the fundamental natural frequency of the water sloshing motion, f_w which is calculated by;

$$f_w = \frac{1}{2\pi}\sqrt{\left[\frac{\pi g}{h}\tanh\left(\frac{\pi h}{L}\right)\right]}$$ for a rectangular tank.

Table 5.2 Comparison of TLD Frequencies

Tank Size		**Water Depth h (mm)**	**Water Depth Ratio (h/L)**	**Fundamental Frequency**	
Length L (mm)	**Width b (mm)**			$f_w = \frac{1}{2\pi}\sqrt{\left[\frac{\pi g}{h}\tanh\left(\frac{\pi h}{L}\right)\right]}$ **(Hz)**	**Experimental (Hz)**
210	80	25	0.12	3.3732	2.8054
210	80	50	0.24	3.1764	2.8054
210	80	75	0.36	2.9284	2.6578
210	80	100	0.48	2.6827	2.7562
210	80	150	0.72	2.2775	2.8546
210	80	200	0.96	1.9896	2.6085

TLD frequencies as calculated from the formula are in good agreement with the frequencies determined experimentally.

5.5 Effect of Depth of Water on Structural Response

The depth ratio, which is the ratio of depth of water h to the tank length L, is a significant parameter for defining the effectiveness of the rectangular TLD.

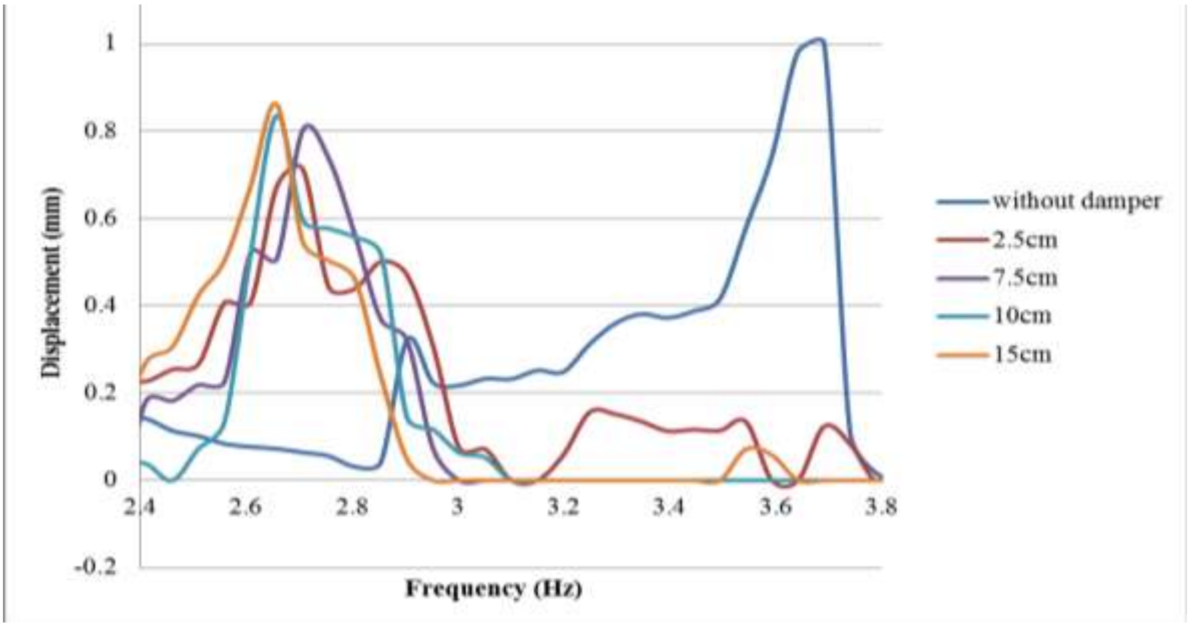


Fig. 5.3 Structural Response Amplitude versus TLD Water Depth

The reason for this trend (Fig. 5.3) can be traced out due to the behaviour of a TLD. The energy absorbed and dissipated by the TLD depends mostly on the sloshing and wave breaking. The TLD having a larger water depth does not slosh as much as that of low water depth, because the energy transmitted to the TLD is relatively low.

5.6 Effect of Mass of Water on Structural Response

The mass ratio which is the ratio of the mass of water to the structural mass is an important parameter which affects the structural response. The mass of the structure is 13.350kg.

Table 5.3 Percentage Reduction in Structural Response by TLD with Different Mass Ratios

Tank Size		**Mass of water (g)**	**Mass Ratio = $\frac{\text{Mass of water}}{\text{structural mass}}$ X 100 (%)**	**Percentage reduction in Displacement (%)**
Length L (mm)	**Width b (mm)**			
210	80	280	2	33.69
210	80	600	4.5	39.04
210	80	910	7	64.46
210	80	1850	14	71.33

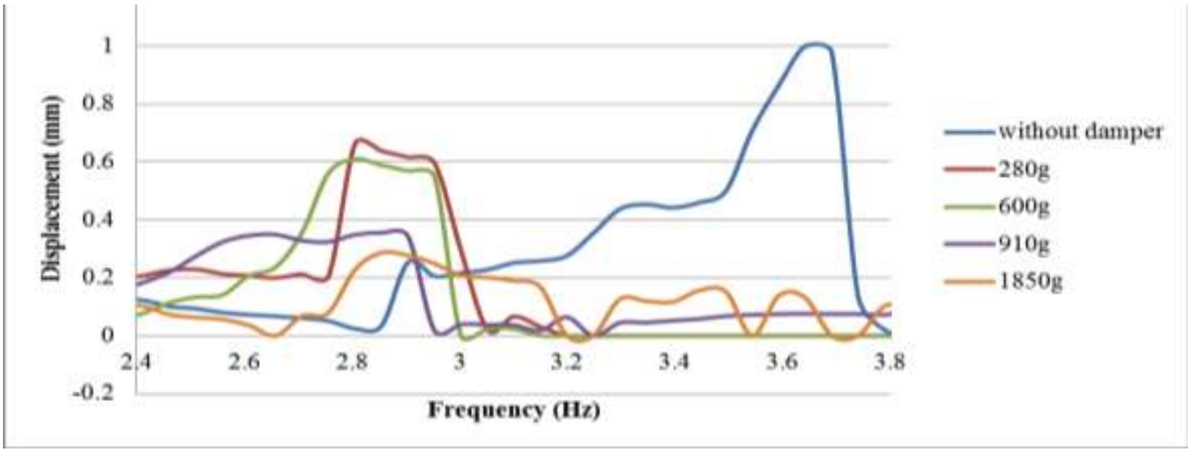


Fig. 5.4 Structural Response by TLD with Different Water Masses

From Table 5.3, it can be observed that the efficient reduction in displacement increased as the mass ratio increased. Fig. 5.4 depicts the structural response by TLD with different water masses.

VI. CONCLUSION

The basic aim of this thesis was to determine the effectiveness of Tuned Liquid Damper for controlling vibration of the structure. The thesis includes finite element modelling and analysis and experimental verification. The effectiveness of the TLD is calculated in terms of the displacement of the story of the structure.

The following conclusions were drawn from the thesis:

- The natural frequency obtained from the finite element analysis and experimental study display good agreement for the undamped structural model.
- It was observed that there is an increase in effective damping of the combined system when the main system is coupled with tuned liquid damper.
- TLD frequencies as calculated from the formula of linear water sloshing frequency are in good agreement with the TLD frequencies determined experimentally.
- Damping reduces as the depth of liquid in the TLD increases as the liquid sloshing and wave development and breaking decreases since the entire mass of water in the damper does not contribute to sloshing.
- Damping effect of the TLD increases with mass ratio.
- It has been found that TLD is capable of controlling vibration of structure effectively

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REFERENCES

[1.] Yozo Fujino, Limin Sun, Benito M. Pacheco, and Piyawat Chaiseri. "Tuned Liquid Damper (TLD) For Suppressing Horizontal Motion of Structures." Journal of Engineering Mechanics, Vol. 118, No. 10. 1992.

[2.] M. J. Tait, N. Isyumov, and A. A. EI Damatty. "Performance of Tuned Liquid Dampers." Journal of Engineering Mechanics, Vol. 134, No.5, 2008.

[3.] Yuxiang Xin, Genda Chen and Lou Menglin. "Seismic response control with density-variable tuned liquid dampers." Earthquake Engineering and Engineering Vibration, Vol.8, No.4. 2009.

[4.] Avik Samanta and Pradipta Banerji. "Earthquake Vibration Control Using Sloshing Liquid Dampers in Building Structures." Journal of Earthquake and Tsunami, Vol.6, No.1. 2012

[5.] Emili Bhattacharjee, Lipika Halder and Richi Prasad Sharma. "An Experimental Study on TLD for Mitigation of Structural Response." International Journal of Advanced Structural Engg. 5:3. 2013

[6.] Tejashri S. Gulve and Pranesh Murnal. "Feasibility of Implementing Water Tank as Passive Tuned Mass Damper." International Journal of Innovative Technology and Exploring Engineering (IJITEE), ISSN: 2278-3075, Volume-3, Issue-3. 2013.

[7.] Jitaditya Mondal, Harsha Nimmala, Shameel Abdulla, Reza Tafreshi. "Tuned Liquid Damper." Proceedings of 3rd International Conf. on Mech. Engg & Mechatronics, Prague, Czech Republic, Aug 14-15, 2014

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