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Parametric Studies on Tuned Liquid Damper by Horizontal Shake Table Experiments

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Abstract: *This paper investigates the performance of a new type of cost-efficient damper for mitigating wind and earthquake induced vibrations in tall buildings. Tuned Liquid Damper (TLD) is a type of Tuned Mass Damper (TMD) where the mass is replaced by a liquid (usually water). A TLD relies upon the motion of shallow liquid in a rigid tank for changing the dynamic characteristics of a structure and dissipating its vibration energy under harmonic excitation. The effectiveness of TLD is evaluated based on the response reduction of the structure which is a two-storied steel building frame. Various parameters that influence the performance of TLD are also studied.*

Keywords - *Earthquake Response, Sloshing, Tuned Liquid Dampers, TLD Parameters, Vibration Control*

I. Introduction

Modern tall buildings are often susceptible to excessive horizontal excitation due to their light weight construction and flexibility and low inherent damping. In addition to structural failure possibilities, issues such as functional performance and human discomfort are major concerns. To improve the design and performance of these structures, several design modifications are available. One of the most promising alternatives is to add external damping devices to the structure.

Tuned Liquid Dampers are structural vibration control device. Tuned Liquid Damper (TLD) is a special class of Tuned Mass Damper (TMD) where mass is replaced by liquid. The sloshing of the liquid in TLD mimics the motion of the TMD mass. TLD comprises of liquid filled tank whose sloshing motion is tuned to the natural frequency of the structure. TLDs are often placed at the top of the structure, and the liquid sloshing action of the TLD when the structure is subjected to external excitation counteracts and reduces the structural vibration.

Previous studies [1] have carried out finite element modelling and analysis of undamped building model in ANSYS WORKBENCH 2015 and based on the mode shapes and frequencies obtained from the analysis, dimensions of the steel building were fixed and experimental study was carried out by shake table experiments for both TLD damped and undamped building model and it was concluded that TLD is effective in reducing structural response. Also, effectiveness of TLD at various liquid depths and mass ratios were also studied. In this paper the viscosity and density of the liquid in the damper are varied in order to study their effect on TLD mechanism and damping. Also energy dissipated is calculated to determine which TLD is most effective in controlling structural vibration.

II. Experimental Setup

The setup consists of a rectangular steel frame with three steel slabs and four steel columns. The frame along with the Tuned Liquid Damper (which is a glass container with liquid) is placed on top of the frame is mounted on to the horizontal shake table driven by an electric motor. The properties of the horizontal shake table are given in Table 2.1. The combined structure is excited to obtain the first two mode shapes. Dimensions of the steel frame and the liquid damper are given in Table 2.2 and Table 2.3 respectively. The displacement response of each floor is measured using accelerometers and which is attached to the data acquisition system. The data acquisition system is connected to the vibration analyzer software to analyze the experimental data. Also frequency vs displacement graph is obtained from the experiment.

Table 2.1 Properties of the Uni-directional Shake Table

Dimension of Sliding Platform	400x400mm
Operating Frequency	0-25Hz
Amplitude Resolution	1mm
Max. Payload	30kg

Table 2.2 Geometric Data of the Steel Frame

Sl.No	Parts	Dimensions in mm		
		Depth (D)	Width (B)	Length (L)
1.	Column	5	25	1200
2.	Slab	8	150	300

Table 2.3 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 model is subjected to base excitation to determine the structural response when:

(i) the structure is in its undamped state (Fig 2.1),

(ii) the structure is damped with Tuned Liquid Damper(Fig 2.2):

a. Traditional TLD (Fig 2.3),

b. Viscous TLD (Fig 2.4),

c. Density variable TLD(Fig 2.5)

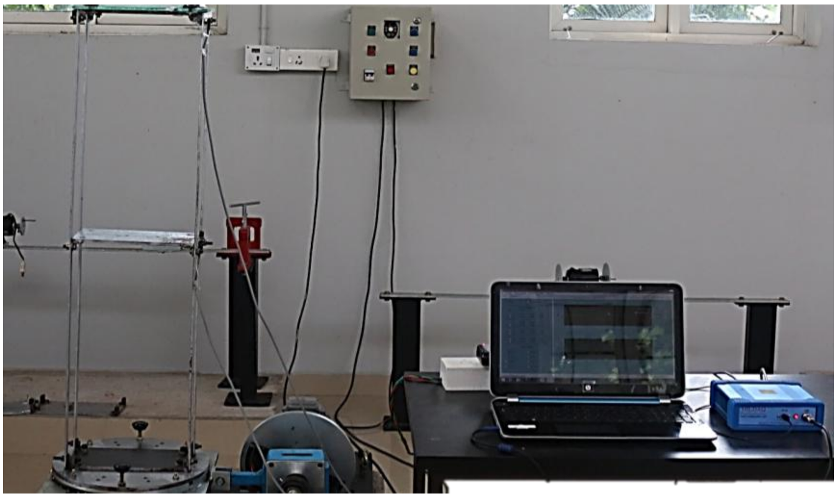

Fig 2.1 Experimental Setup of Undamped Structural Model

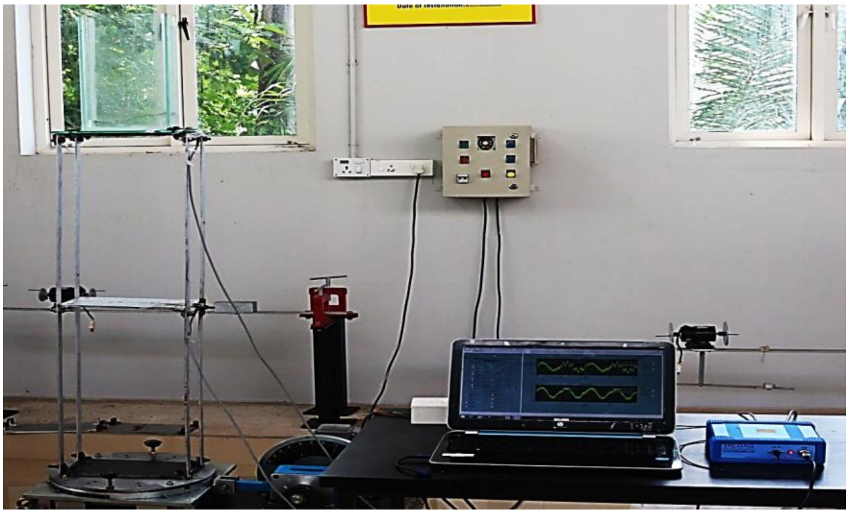

Fig 2.2 Experimental Setup of the Structural Model Damped with TLD

Fig 2.3 Traditional TLD (consisting of water as liquid)

Fig 2.4 Viscous TLD (consisting of oil)

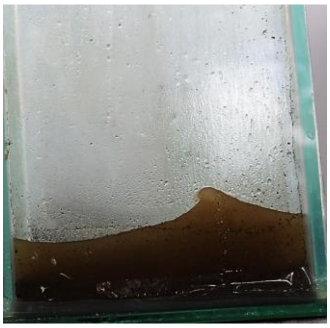

Fig 2.5 Density Variable TLD (consisting of sand and water)

III. Results And Discussions

The main objective of this experimental study is to investigate the behaviour of water sloshing motion and effects of liquid viscosity and density on the sloshing behaviour. Also the amount of energy dissipated is an important parameter included in this study.

3.1 Structural Response of an Undamped System

When the undamped structure is subjected to horizontal excitation, the displacement response of each floor is measured. First and second mode shapes obtained from the experiment are shown in (Fig 3.1) and (Fig 3.2).

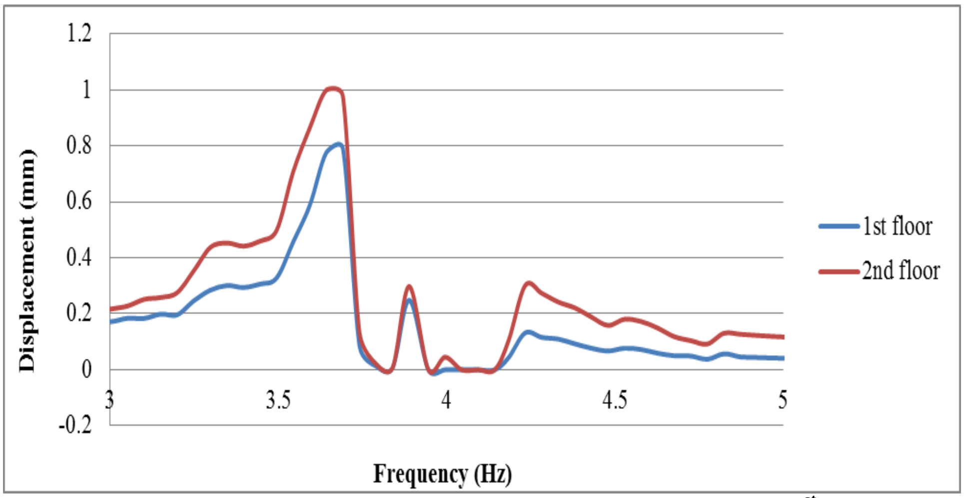

Fig 3.1 Structural Response of the Undamped System showing 1st Mode

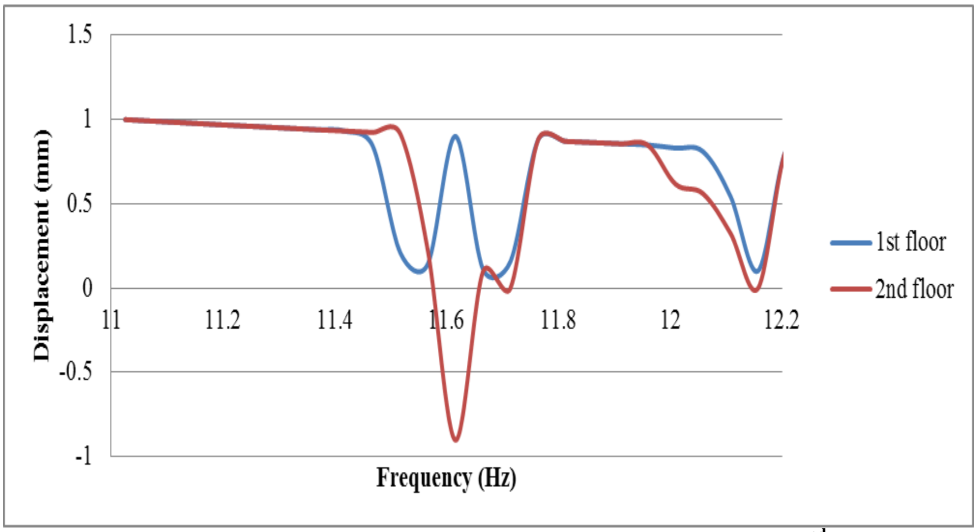

Fig 3.2 Structural Response of the Undamped System showing 2nd Mode

3.2 Structural Response of Damped and Undamped Model

Horizontal shake table experiments were conducted for both damped and undamped systems to determine the effect of damper in reducing structural response.

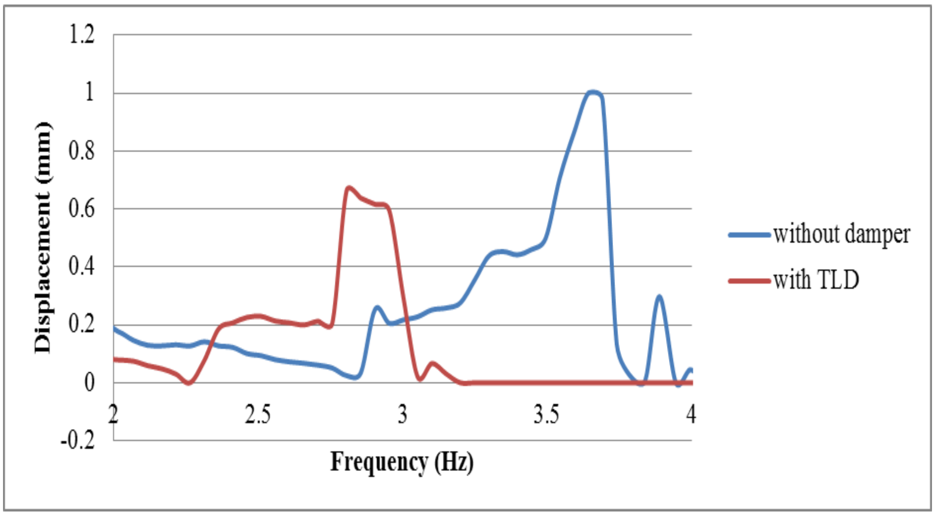

Fig 3.3 Structural response of the Undamped System and the System Damped with TLD.

From Fig 3.3, we observe that there is an increase in effective damping of the combined system when the main system is coupled with the damper.

3.3 Effect of Liquid Viscosity on Structural Response

The effect of structural response of an undamped structure and structure damped with traditional TLD and TLD with oil are studied experimentally as shown in Fig 3.4.

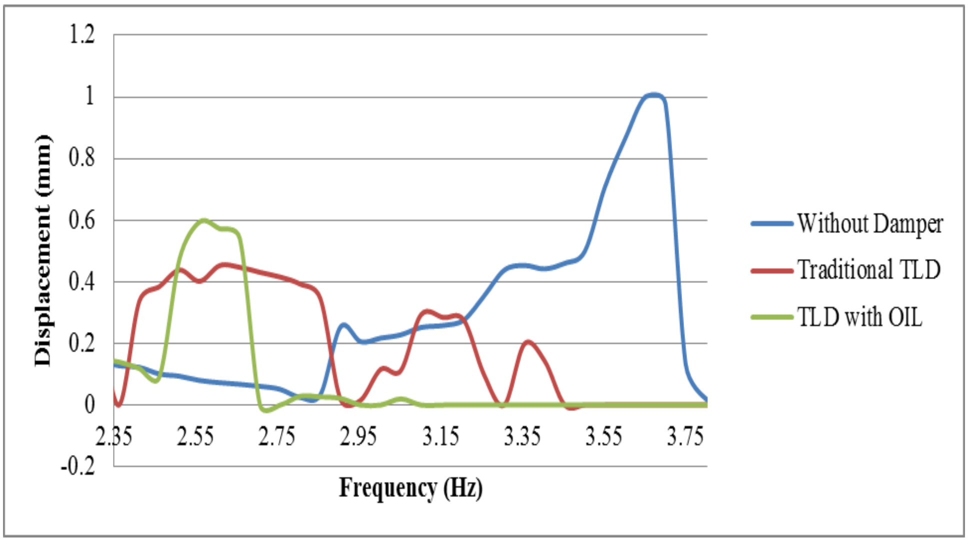

Fig 3.4 Effect of Liquid Viscosity on Structural Response.

From the above graph (Fig 3.4), it is observed that damping with traditional TLD is more effective than TLD with oil due to higher viscosity due to which sloshing is decreased. Thus high-viscosity liquid is not preferable in a TLD since it inhibits the development and breaking of high waves.

3.4 Effect of Liquid Density on Structural Response

The floor displacement responses of the undamped and damped structure are measured. Two damped conditions are compared: one with a traditional TLD and a TLD with water and sand mixture.

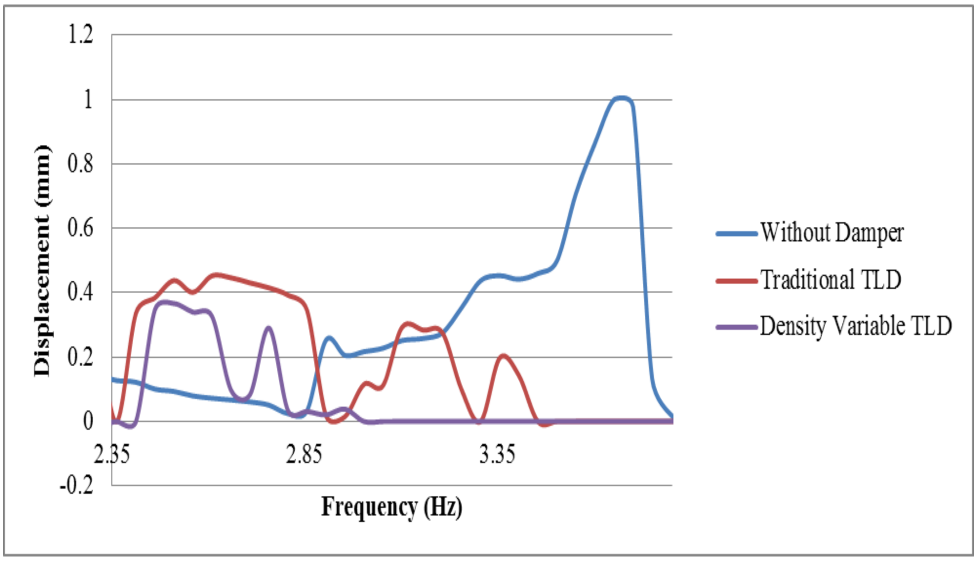

Fig 3.5 Effect of Liquid Density on Structural Response .

It is observed from Fig 3.5 that the sand particles initially sink in the tank. They will remain at the bottom of the tank and only the water at the free surface will slosh when the tank is subjected to a weak base excitation. As the base excitation increases, the sand particles appear in a liquefied state because of the increase in pore pressure between the particles; the liquid and the particles are thus mixed and sloshed together. Since the density increases with the base excitation, the device is referred to as a density-variable damper.

Thus TLD with water-sand mixture is more effective than a traditional TLD due to an increase of the mass density of sloshing water and sand mixture which results in accelerating the decaying process of vibration due to increased damping.

3.5 Comparison of Effect of Various Dampers on Structural Response

The effect of various dampers on the structural response are studied and compared with the structural response of an undamped system.

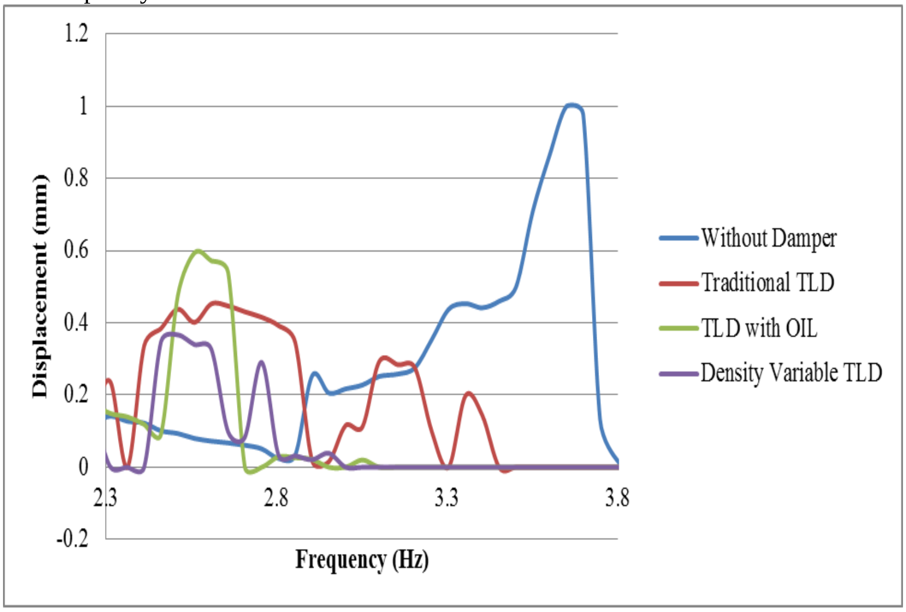

Fig 3.6 Effect of Various Dampers on Structural Response

From the graph (Fig 3.6), it is observed that maximum structural displacement is obtained for an undamped system and displacement is reduced with the TLD.

3.6 Comparison of Energy Dissipation

Energy dissipation is calculated as difference in area under the curve of the frequency versus structural displacement plot of undamped and damped structure.

Table 3.1 Maximum and Minimum Energy Dissipated in Each Floor by Damped Structures

Damper	Min. Energy Dissipated		Max. Energy Dissipated	
	First Floor	Second Floor	First Floor	Second Floor
Traditional TLD (with water in TLD)	22.6063	32.4735	33.4481	41.0583
TLD with oil as liquid	13.7134	15.6822	29.8889	37.9912
Density variable TLD (with water and sand in TLD)	15.0455	23.8356	49.1197	62.9936

From table 3.1, it is noted that maximum energy is dissipated by density variable TLD. Hence it can be concluded that TLD is more effective in reducing structural response. Also among various TLDs, density variable TLD is most effective in energy dissipation thereby reducing the structural displacement.

IV. Conclusions

The basic aim of this thesis is to determine the effectiveness of Tuned Liquid Damper for controlling vibration of the structure. The effectiveness of the TLD is calculated in terms of the displacement of the story of the structure.

The following conclusions are drawn from the study:

- It is observed that there is an increase in effective damping of the combined system when the main system is coupled with tuned liquid damper. Structural response can be reduced up to 55% when the structure is damped with TLD.
- It is noted that higher damping is obtained from less viscous liquid; ie water compared to oil. This is because higher viscous liquid inhibit wave development and wave breaking. Only 40% structural displacement can be reduced with TLD consisting of oil which lesser compared to traditional TLD which can reduce up to 55%.
- For a traditional TLD the water at the free surface will only slosh when subjected to base excitation. The increase in mass density of the sloshing water and sand mixture effectively mitigates the story drift than a traditional TLD since the sand particles appear in liquefied state when base excitation increases thus water and sand particles get mixed and sloshed together. Density variable is more effective than traditional TLD and viscous TLD since about 65% of the displacement response can be reduced.
- Energy dissipation is found maximum when the structure is damped with density variable TLD.

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