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Comparison of Vibration Performance of Modified Tuned Liquid Damper and Friction Damper

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Abstract— Structural response control with various forms of dampers have been a core area of study which was adopted to mitigate various natural hazards like wind and earthquake. Passive auxillary dynamic vibration absorbers have become accepted devices for reducing the resonant motions of lively tall buildings. Tuned Liquid Dampers (TLDs) are passive response control devices that have undergone numerous modifications in its functionality and installation to reduce the structural vibrations during the event of an earthquake. In this study the structural response of a steel frame structure is determined for an undamped system and also for structure damped with modified TLDs. Also the effectiveness of a Friction Damper to control the structural response is studied and compared with that of the TLD.

Keywords— Framed structure, Dynamic Excitation, Tuned Liquid Damper, Friction Damper, Vibration Absorber.

I. INTRODUCTION

Structural reinforcement is defined as the process of increasing the resistance of the structure to dynamic loads. Due to its proven efficiency, the concept of seismic protection based on supplemental damping is gaining momentum within the engineering community. Structural controlling devices withstand shaking effect by absorbing and dissipating energy. In passive devices, oscillations of the entire mechanism affect directly the direction of controlling forces. The energy required for passive systems to create the control forces is produced, not by external influences, but rather through the motion of the mechanism during dynamic excitement.

This paper investigates the performance of Tuned Liquid Damper and Friction Damper under horizontal excitation. Tuned Liquid Dampers and Friction Dampers are often employed as displacement dependent type of passive response control systems because of their high-energy dissipation potential at relatively low cost and they are easy to install and maintain.

The basic mechanism in Tuned Liquid Damper is that, the damping originates in the TLD from energy dissipation through the action of internal fluid viscous force and from wave breaking. The amount of damping is dependent on amplitude of the fluid motion and wave breaking patterns. The motion inside the TLD sloshes at the side of the wall of the TLD tank which in turn produces a force opposite to the excitation direction. The principle of Friction damper is based on the mechanism of friction for dissipation of vibration energy. These devices convert kinematic energy into heat by friction. When the framed structure is excited by a lateral force, it causes horizontal displacement of the structure. The friction forces between the rubber pads and the steel rings would resist the horizontal displacement. Thus the input energy of the frame is dissipated through conversion of kinetic energy into thermal energy by the rubber pads and steel rings.

In previous paper [1] horizontal shake table experiments was conducted to determine the effectiveness of traditional TLD 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 another paper [2] the viscosity and density of the liquid in the damper were 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. And it was concluded that Density variable TLD is most effective in controlling structural response. In this paper, the structural response control of various TLD is compared with that of the Friction Damper.

II. EXPERIMENTAL SETUP

The dimensions of the steel building frame was fixed through finite element modeling in ANSYS and horizontal shake table experiments were carried out for undamped frame and structure damped with Tuned Liquid Damper.

The operating frequencies of the shake table range from 0 to 25 Hz. Finite Element Analysis was carried out to determine the natural frequencies and modes of the two storey structure such that the first tow mode shapes of the finite element model ranges between 0 to 25 Hz. Thus the dimensions of the steel frame were fixed for conducting vibration experiment [1]. Also effects of various parameters that influence damping were considered such as liquid depth, mass of liquid. Effect of liquid viscosity and density on the performance of TLD to reduce displacement response is also considered [2]. And energy dissipated in each case is determined.

The setup is mainly a rectangular steel frame with three steel slabs connected to four steel columns. The frame along with the Tuned Liquid Damper (which is a glass container with liquid) and Friction Damper is placed on top of the frame is mounted on to the horizontal shake table driven by an electric motor. The combined structure is excited to obtain the first mode shape in each damped case. 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. Dimensions of the steel frame are given in Table 1.

TABLE I

DIMENSIONS 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

Tuned Liquid Damper is a glass container with shallow water (Fig. 1) is used as damper for the structure. The geometric property of the Liquid damper is shown in Table 2. The tank is placed at the top of the structure.

Fig. 1 Liquid Damper

TABLE III

GEOMETRIC DATA OF THE TUNED LIQUID DAMPER

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

The friction damper (Fig. 2) consists of a rubber bearing and two steel bearings which when rotated by a D C motor. The D C motor rotates the bearings by means of a rotating axle which has a diameter of 8mm. The dimensions of the bearings are given in Table 3. The speed of the D C motor is regulated by adjusting the voltage in the voltage regulator. The properties of the D C motor are provided in Table 4. The damper is placed at the top of the structure.

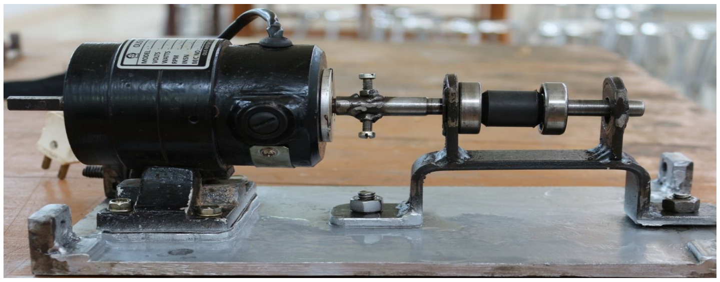


Fig. 2 Friction Damper

TABLE IIIII
DIMENSIONS OF THE BEARINGS

Parts	Internal Diameter (mm)	External Diameter (mm)	Depth (mm)
Steel Bearing	10	31	10
Rubber Bearing	12	23	3

TABLE IVV
PROPERTIES OF THE DC MOTOR

Mass	2.85 kg
Volts	2.4 V
Watts	80 W
RPM	3000

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

- *A.* the structure is in its undamped state,
- *B.* the structure is damped with Tuned Liquid Damper:
  - *1)* Traditional TLD (Fig. 3),
  - *2)* Viscous TLD (Fig. 4),
  - *3)* Density variable TLD(Fig. 5)
- *C.* the structure is damped with Friction Damper

Fig. 3 Traditional TLD (consists of water as liquid)

Fig. 4 Viscous TLD (consists of oil)

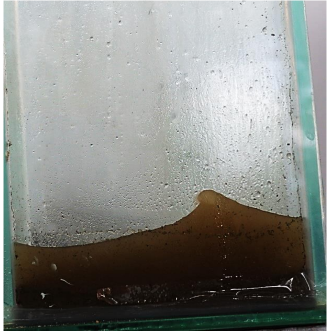


Fig. 5 Density Variable TLD (consists of sand and water)

III.RESULTS AND DISCUSSIONS

The primary objective of this study is to investigate the behaviour of the structure when it is damped with Tuned Liquid Damper and Friction Damper. Also to compare the energy dissipated in both cases.

A. Comparison of Structural Response of Damped and Undamped Model

To understand the effect of damping, shake table experiments were conducted for both damped and undamped systems.

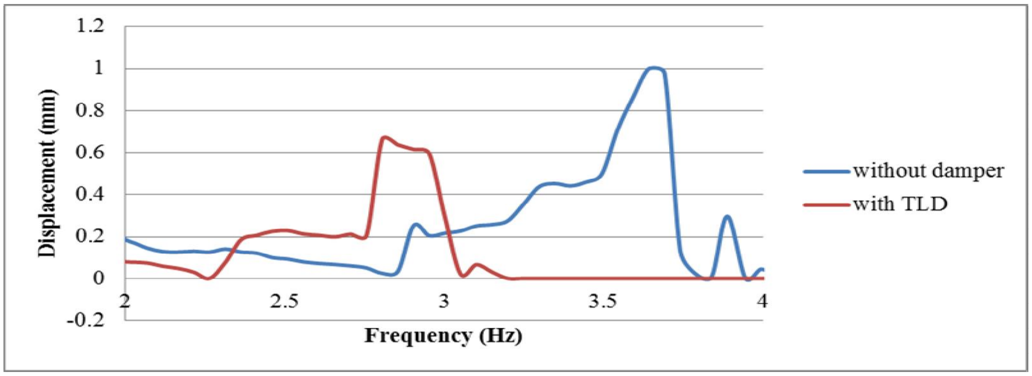
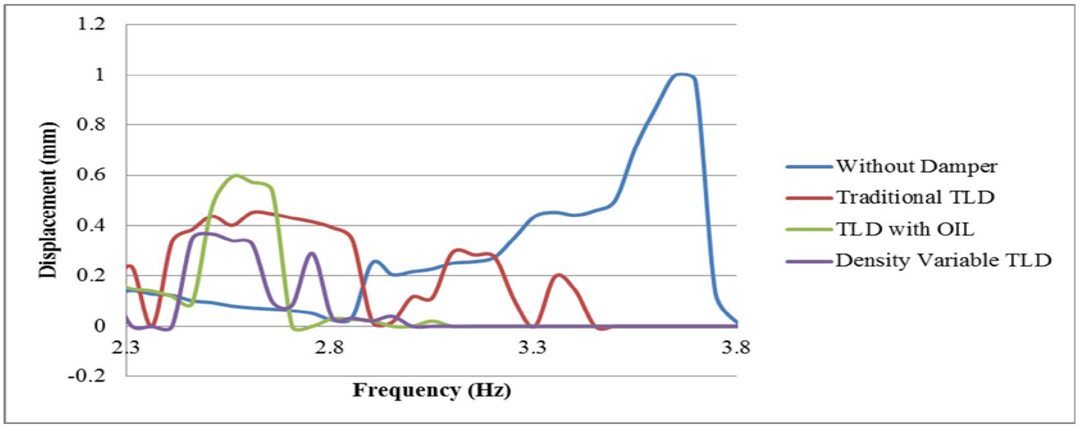


Fig. 6 Structural response of the Undamped System and the System Damped with TLD

Fig. 6 shows the first mode shape of the structure when it is undamped and damped with TLD. We observe that there is an increase in effective damping of the combined system when the main system is coupled with the damper.

B. Comparison of Effect of Various TLDs on Structural Response



Fig, 7 Effects of Various TLDs on Structural Response

In Fig. 7, the effects of various Tuned Liquid Dampers on the structural response are studied and compared with the structural response of an undamped system. 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.

In 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.in accelerating the decaying process of vibration due to increased damping.

C. Effect of Friction Damper on Structural Response

To understand the effect of Friction damper, shake table experiments are conducted for both undamped system and system damped with Friction damper.

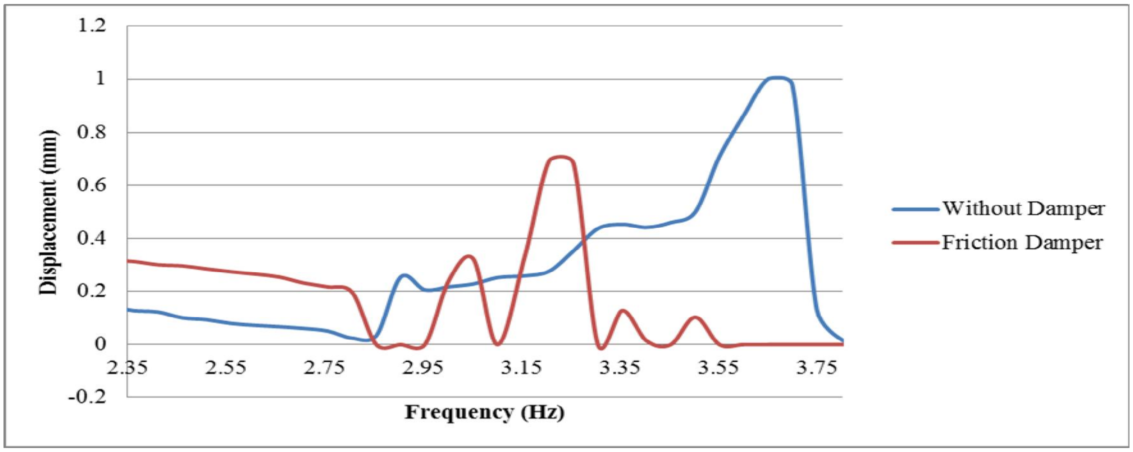


Fig. 8 Structural Response of the Undamped System and the System Damped with Friction Damper

From Fig. 8, it is observed that the structural displacement is reduced when the structure is damped with friction damper since the energy is dissipated through friction. Thus kinetic energy is converted and dissipated through thermal energy created by the friction between the steel and rubber bearings in the Friction damper.

D. Comparison of Effect of Various Dampers on Structural Response

The effect of the TLDs and Friction Damper on the structural response is studied and compared with the structural response of an undamped system.

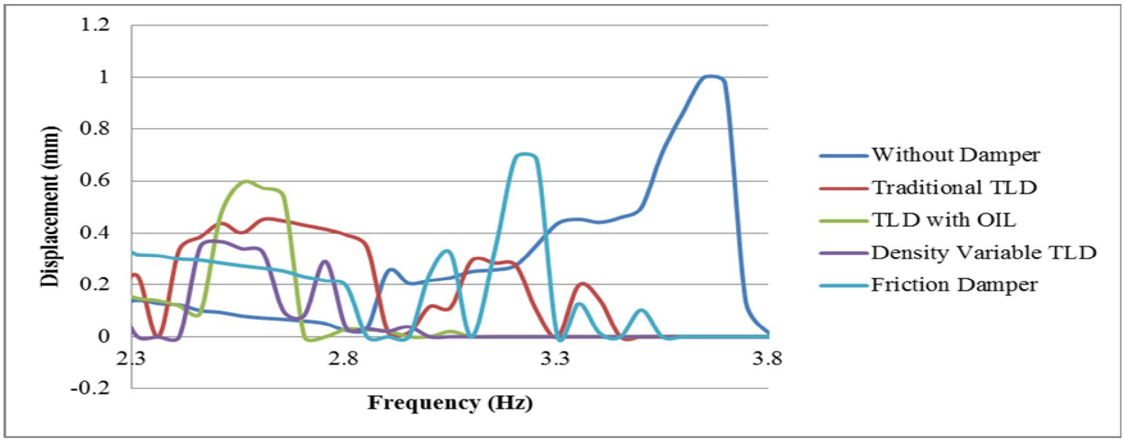


Fig. 9 Effect of Various Dampers on Structural Response

From the graph (Fig. 9), it is observed that maximum structural displacement is obtained for an undamped system and displacement is reduced with the TLD and friction damper. However, it is seen in the graph that TLD effectively reduces structural displacement in comparison to friction damper since more energy is dissipated through sloshing liquid than energy dissipated through friction.

This is because damping by TLD involves wave developing and breaking due to the high force exerted by the liquid in the TLD on the damper walls.

E. 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. Energy dissipated by TLDs and Friction Damper is compared in Table 5.

TABLE V
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
Friction Damper	13.2911	24.4448	13.2911	24.4448

It can be noted that maximum energy is dissipated by density variable TLD whereas min. energy is dissipated by friction damper. Hence it can be concluded that TLD is more effective than friction damper 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 paper is to determine the effectiveness of various Tuned Liquid Dampers and Friction Damper for controlling vibration of the structure. The effectiveness of the damper is calculated in terms of the displacement of the story of the structure. The following conclusions are drawn from the thesis:

A. There is an increase in effective damping of the combined system when the main system is coupled with damper.
B. It is observed that increase in mass density of the sloshing water and sand mixture in the Density Variable TLD 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. Also, 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. Thus from the plot (Fig. 7), about 65% of the displacement response of the framed structure is reduced when the structure is damped with Density Variable TLD.
C. There is considerable reduction in structural displacement when it is damped with friction damper since the energy is dissipated through friction between the roller bearing in the friction damper.
D. TLD presented more effective results in reducing structural response when compared to the Friction damper. Also it is observed that TLD dissipates more energy than Friction Damper. Friction damper can reduce only about 30% (Fig. 8) of the displacement response of the frame.
E. Energy dissipation is found maximum when the structure is damped with density variable TLD.
F. Thus TLD is capable of controlling vibration of structure effectively.

V. ACKNOWLEDGMENT

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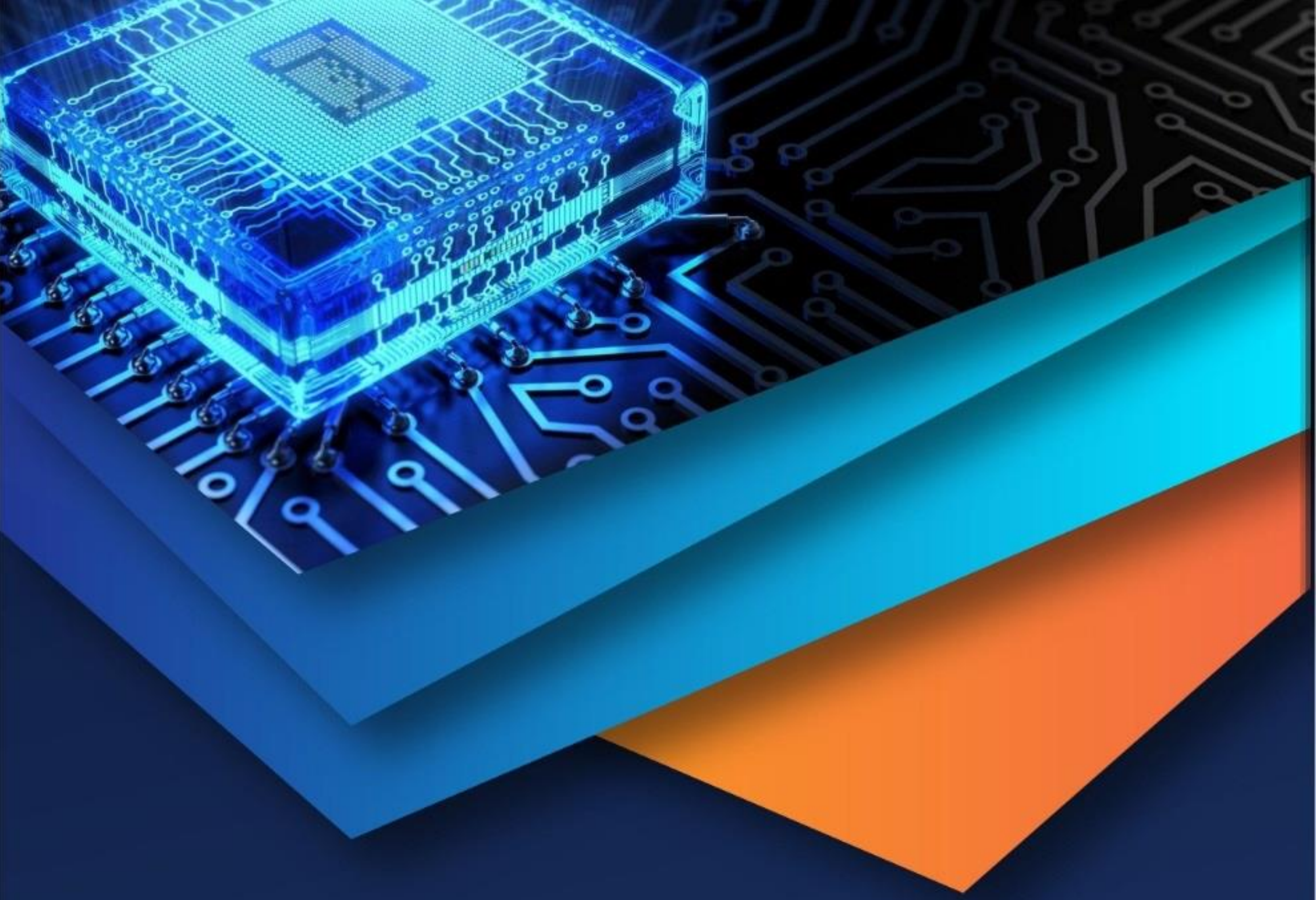

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