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Application of Tuned Liquid Damper on Response of a Building under Strong Ground Motion

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Abstract— Modern construction industry demands an effective method for controlling the vibrations of taller and lighter structures. The tuned liquid damper is one such effective method to minimize the vibrations of the structure. It is Cost effective and demands less maintenance. In this paper an analytical study is proposed on the effectiveness of tuned liquid damper under earthquake to reduce structural vibration of a multi storied building using FEAST. Primarily, modeling of structure was done and free vibration analysis was executed to determine the fundamental natural frequency. Then the tuned liquid damper is to be designed for the natural frequency of building and the frequency response analysis were carried out under 1m/s2 base excitation. The optimum mass ratio obtained was 1.5 % and corresponding reduction in acceleration was found to be 32.93%. Then shock response spectrum analysis were carried out by considering data from 4 major earthquakes and the corresponding reduction in displacement (54.62%) were recorded. Finally optimum dimensions of the tank suitable for practical implementation were recommended.

Index Terms— earthquake, energy dissipation, mass ratio, response, shock, sloshing, Tuned Liquid Dampers.

1 INTRODUCTION

NOWADAYS, there is an increasing trend to construct tall structures, to minimize the increasing space limitations in urban areas. But the response of these structures due to environmental forces makes it vulnerable, which led to the advancement of the controlled devices in the recent past .The vibration due to building forces can be controlled by the modification of rigidity, mass, damping, shape etc of the structure. The selection of a particular type of vibration control devices is governed by a number of factors which include efficiency, compactness and weight, capital cost, operating cost, maintenance requirement and safety. Damping being an effective method to control effect of vibration remains as big challenge to engineers. Supplemental damping systems can be classified into active, semi-active and passive control.

Tuned liquid damper, a passive controlling method, which dissipate energy without using an external power source. It is proposed by Bauer [1] in 1980s. TLD's are further more classified into Tuned Sloshing Dampers (TSD's), Tuned Liquid Column Dampers (TLCD's) and controllable TLD's. TSDs are basically partially filled rectangular or circular tank which have low installation, running, maintenance and operation cost, fewer mechanical problem etc. that makes TSDs preferable option than other damping devices. Moreover TSD tanks can be used as swimming pools fire storage tanks and it can be installed in existing buildings.

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When the tank is excited through structural motion, the fluid in the tank begins to slosh, imparting inertial forces to the structure, out of phase with the structural motion, thereby reducing the movement.

The objectives of this paper is to reduce the structural response by installing a model of TSD attached to the structure subjected to horizontal base excitations and to study the effects of mass ratio to the structural response.Also conduct shock reponse analysis by considering actual earthquake data. Finally recommend the suitable tank dimensions for practical implementation.

2 DESCRIPTION OF THE TESTED BUILDING

A 25-storey irregular reinforced concrete irregular building with a height of 78 meters (each storey -3m) was considered in this study. The finite element modeling and analysis of the building frame was performed using FEAST.The material properties of various elements of the model as shown on table 1.

TABLE 1
MATERIAL PROPERTIES CONSIDERED FOR THE MODEL

Material	Density (kg/m3)	Modulus of elasticity (N/m2)	Poisson's ratio
Reinforced concrete	3880	3.31E +10	0.15

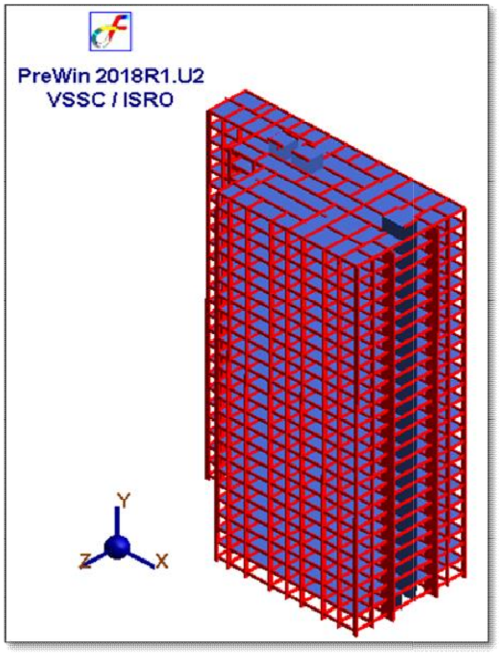

Fig.1. 3-D model of the building studied

3 Free Vibration Analysis of the Structure

Natural frequencies and mode shapes of the structure are found out from the free vibration analysis. The data collected from the free vibration analysis are the basic dynamic characteristics of the structure and the input details for the design of a damping system.

The initial Frequencies (Table 2) and mode shapes (Figure 2, 3, 4) obtained from the free vibration analysis are as shown below.

TABLE 2
Natural Frequencies of various modes

Mode	1	2	3	4	5
Frequency	0.345	0.3884	0.447	1.095	1.236

Mode	6	7	8	9	10
Frequency	1.476	1.966	2.345	2.851	2.892

As mentioned earlier that a structure can have many modes of frequency, there will be a particular frequency which is dominant for the whole structure. This dominant frequency will produce the maximum effect (deflection) on the structure compared to other frequencies. The fundamental frequency from normal mode analysis is obtained as 0.3451 Hz.

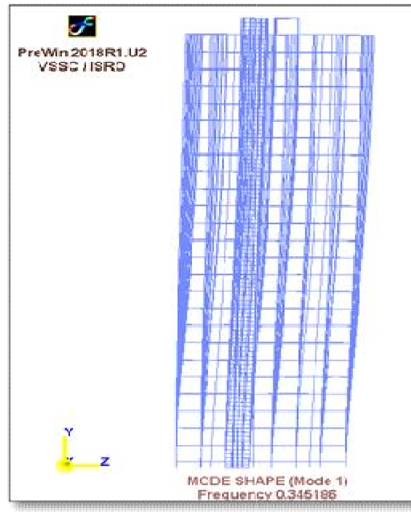

Fig.2. mode1 (bending in Z direction)

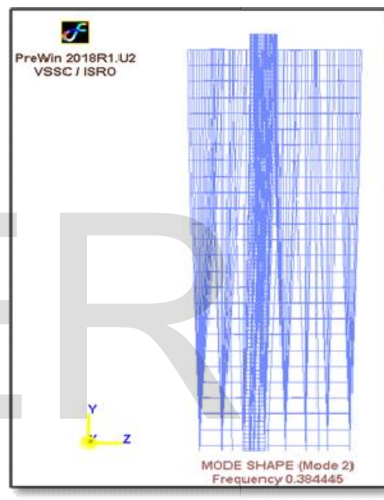

Fig.3. mode2 (Torsion)

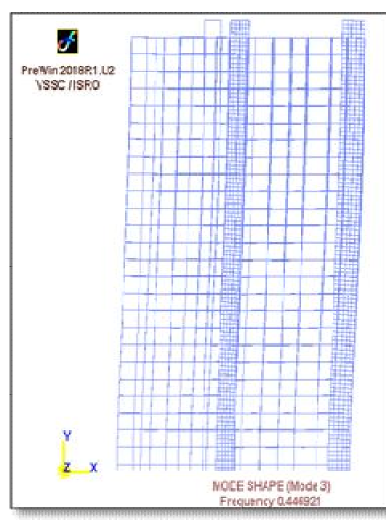

Fig.4. mode 3 (bending in X direction)

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4 Frequency Response analysis

Frequency response analysis is a method used to compute structural response to steady state oscillatory excitation. In frequency response analysis the excitation is explicitly defined in the frequency domain.The differences in phase between building and damper allows the effective dissipation of energy. Also the maximum phase difference occurs when the TLD is tuned exactly to the natural frequency of the building. At this condition, there is 90 degree phase difference between building and damper. A base excitation of 1 m/s2 was provided at all supports of the building in the shortest direction. From IS 1893: 2002, the damping of the structure is selected as 5%.

From frequency response analysis, the acceleration- frequency curve was obtained for a top node. The acceleration obtained was 11.261 m/s2 (Figure 1.5) for the fundamental frequency which are to be reduced by introducing damping system.

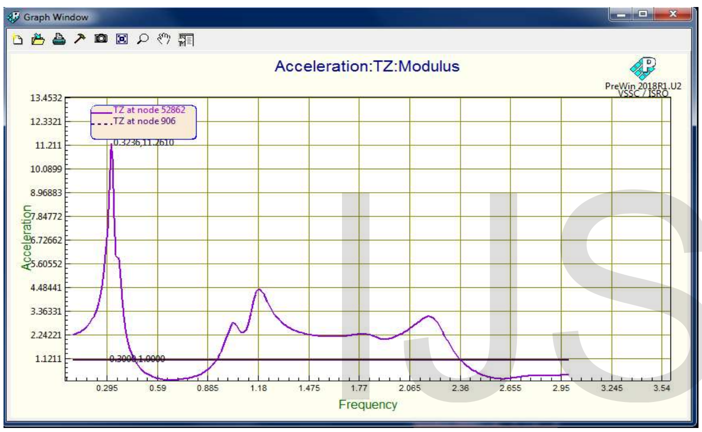

Fig.5. Frequency response of top node and base node

From numerical solutions the response of a structure that is acceleration under unit excitation can be calculated using the equation below.

$$\text{Response} = \text{MPF} \times \frac{\varphi}{2\times\xi}$$

Where MPF is the modal participation factor that is the square root of effective mass corresponding to mode 1, φ is the mode value corresponding to the selected node,$\xi$is the damping coefficient. Here,

$$\text{MPF}= \sqrt{14591760} = 3819.91$$

$$\varphi = 0.000232126, \xi = 0.05$$

$$\text{Response} = 3819.91 \times \frac{0.000232126}{2\times0.05} = 11.18\text{m/s2}$$

Therefore numerical and analytical results are comparable.

Equivalent Mechanical Model Formation of TLD

The vibrations may be reduced by attaching a secondary mass through a suitably selected spring and damper. The tuning of the spring and damper to produce optimal reduction is an important feature.

Optimization of Mass Ratio ( )μ

$$\mu = \frac{Ms}{Meff}$$

Where Ms is the slosh mass and meff is the effective mass of the structure

Effective mass of the building for the first mode =14591760 kg

Thus sloshing mass can be calculated using above equation with different mass ratios. Corresponding spring constant 'k' can be calculated using the equation.

$$f = \frac{1}{2\pi} \times \sqrt{\frac{k}{m}}$$

The slosh masses and spring constants corresponding to various mass ratios as shown in table 3.

TABLE 3
Slosh Mass And Spring Constant For Different Mass Ratios

Sl No.	Mass Ratio, (%)	Slosh mass, Ms (kg)	Spring constant, k
1	0.5	72958.8	343197.223
2	1	145917.6	686393.47
3	1.5	218876.4	1029590.20
4	2	291835.2	1372786.94
5	2.5	364794	1715983.68
6	3	437752.6	2059177.59
7	3.5	510711.6	2402377.152

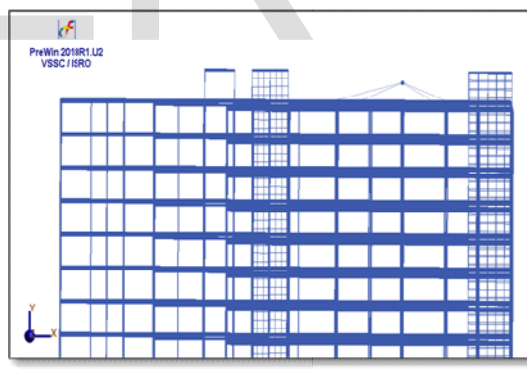

Fig.6. Model with spring mass system

The response reduction of TLD equipped building uner different mass ratios are shown in table 3.

TABLE 4
Response Reduction with different Mass Ratios

Sl no.	Mass ratio	Without TLD	With TLD	Percentage reduction
1	0.50%	11.26	8.14	27.70
2	1%	11.26	8.02	28.70
3	1.50%	11.26	7.55	32.93

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4	2%	11.26	7.88	29.95
5	2.50%	11.26	7.70	31.58
6	3%	11.26	7.53	33.13
7	3.50%	11.26	7.45	33.82

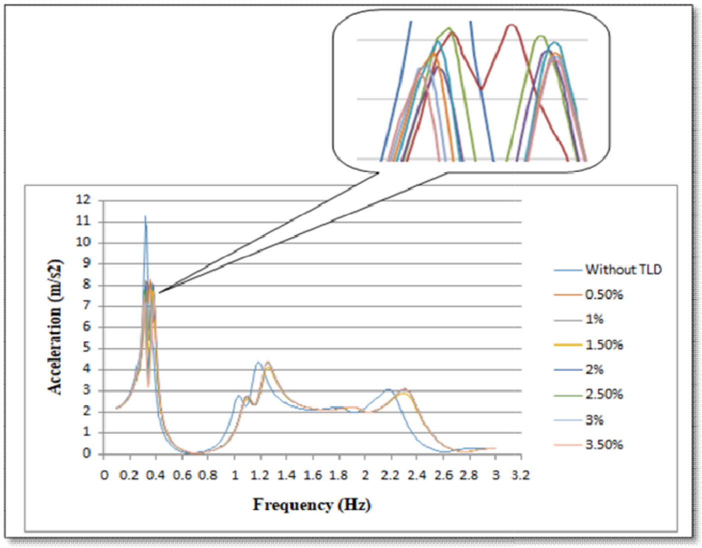

Fig.7. Response of the building without TLD and with TLD at different mass ratios

It was found that the maximum peak acceleration 11.26m/s2 was reduced when the dampers were installed. It was found that there was considerable reduction in the maximum peak amplitude for mass ratios 0.5, 1, 1.5, 2, 2.5, 3 and3.5 %. After 1.5% mass ratio, it was found that the reduction in response for the remaining mass ratios were almost same, the differences very marginal. Also, from structural perspective, it is advisable not to provide any extra mass in the building greater than 2 %. Thus 1.5 % mass ratio is taken as the most optimum considering the structural, damping and economy factors. The reduction in maximum amplitude achieved was 32.93 %.

5 Shock Response Analysis

Shock tests are performed to verify that a structure or a device can support transient vibrations encountered during its life in real environmental conditions. One of the shock testing formats is the Shock Response Spectrum. Shock Response Spectrum (SRS) analysis is, by definition, the maximum response of a series of Single Degree Of Freedom (SDOF) systems of same damping to a given transient signal. These SDOF systems are selected as a reference to analyse transient phenomena.

In this study the shock response spectrum for 4 largest earthquakes considered. They are EL- Cemtro earthquake, Bhuj earthquake, Uttarkashi earthquake and Chamoli earthquake. Then shock response spectrum was created individually for all earthquakes and take an overall envelop for the input of shock response analysis. They are shown in fig 8 below. Displacement of building without TLD and with optimized TLD after shock was given figures 9 and 10.

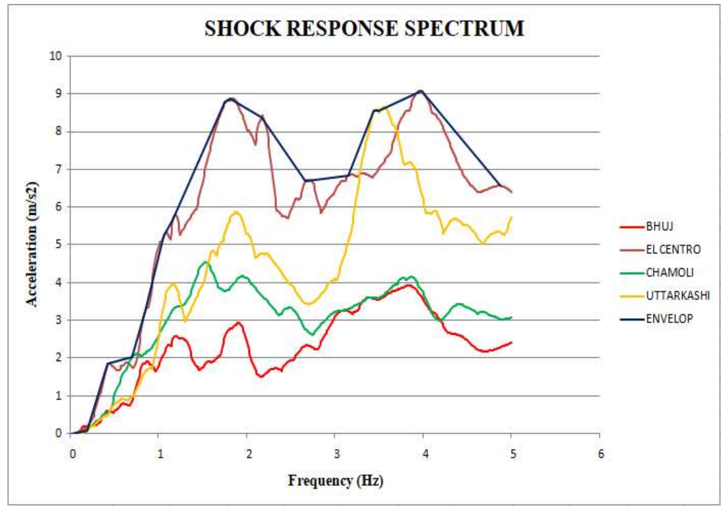

Fig.8. Shock Response Spectrum of different earthquakes

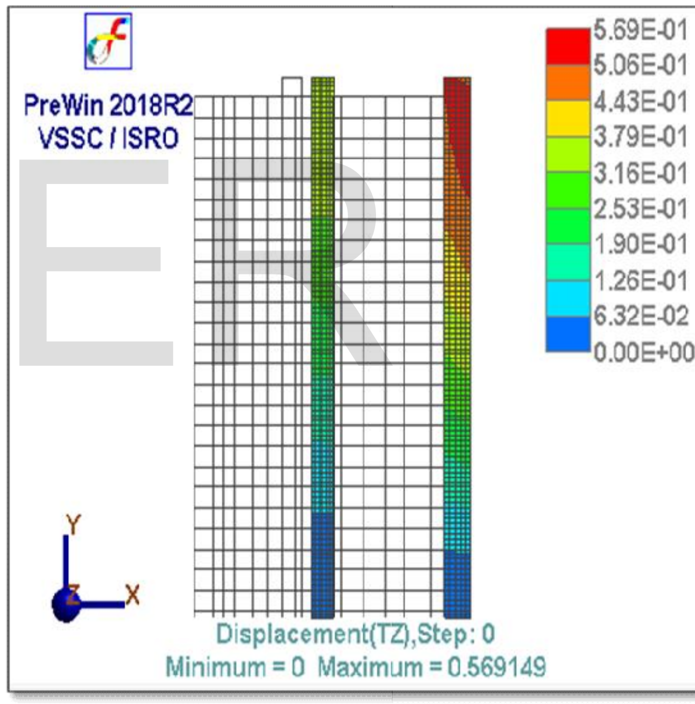

Fig.9. Displacement of building without damper after shock

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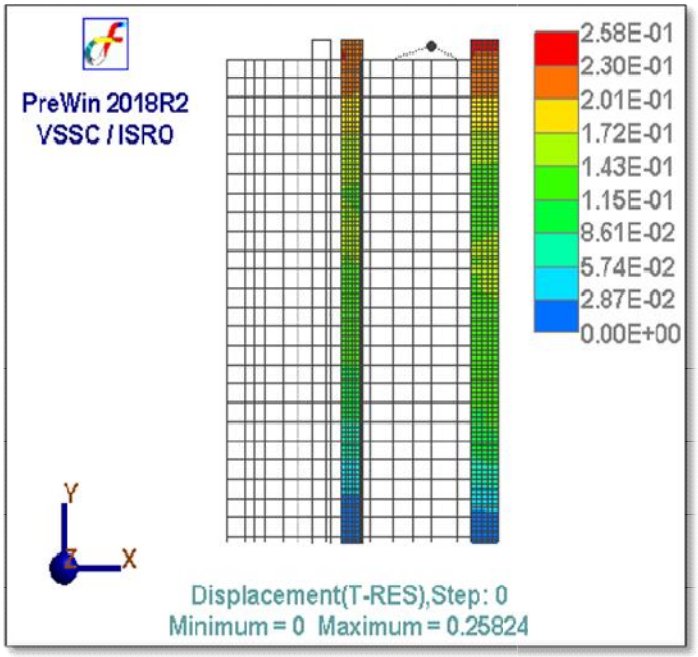

Fig.10. Displacement of building with damper at optimized mass ratio after shock

From shock response analysis the reduction in maximum sisplacement achieved was 54.62 %. Therefore TLD is an effective method to contro the structural vibrations due to shock.

6 Practical Implementation of TLD

Tuned sloshing damper is a liquid containing structure; rectangular or cylindrical in shape. These are generally attached to the top most floor of the building. The height of liquid in the container is so adjusted that its fundamental natural frequency in sloshing motion is tuned to one of the natural frequency of the structure. Due to the importance of water, tank on top of a building it can be effectively used as a swimming pool or fire fighting tank and efficient vibration absorber. So Based on the optimum mass ratio obtained, following dimensions are required for the tank and water depth for the structure to control vibrations effectively.

TABLE 6

Practical implementation of Circular Tank

Sl no.	CASE	Diameter of the tank (m)	Height of water (m)	Total mass of liquid (Kg)	Slosh mass of liquid in tank (Kg)	Slosh mass required (Kg)	Remarks
1	Single TLD with 1.5% mass ratio	14	1.828	281398.73	218937.34	218876.4	On right top of the building

TABLE 5

Practical implementation of Rectangular Tank

Sl no.	CASE	Width of the tank (m)	Length of the tank (m)	Height of water (m)	Total mass of liquid (Kg)	Slosh mass of liquid in tank (Kg)	Slosh mass required (Kg)	Remarks
1	Single TLD with 1.5% mass ratio	11.5	18	1.635	338445	218968.5	218876.4	On right top of the building

7 Conclusions

Earthquake control of a 25 storey benchmark building installed with Tuned Liquid Damper as per modal frequencies and mode shapes are investigated using FEAST software. A comparison of the response of the buildings installed with the TLD at top floor with optimized mass ratio is made. Top node acceleration of the building under frequency response analysis was found to be 11.26 m/s2 and it was comparable with numerical result (11.18 m/s2). The attempts made to optimize the mass ratio of TLD's for the particular structure was found that the most optimum mass ratio would be 1.5 % considering the structural, damping and economy factors. 32.93 % of response reduction was found during earthquake at optimized mass ratio. Shock response spectrum of 4 major earthquakes was created using Feast software and their envelop was given for shock response analysis.In shock response analysis 58.69 % displacement reduction was found by installing optimised TLD in the building. Finally Practical dimensions of TLD tank were found out for optimum case by considering rectangular and circular shapes.

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