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Seismic Analysis of G+5 Building Using Water Tank as Tuned Liquid Damper

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Abstract: Using water tanks at roof as counteraction solutions, which are known as Tuned Liquid Dampers (TLD), in this paper six story building is considered. TLD is modelled by using Etabs 2016 software for a regular (G+5) storied OMRF building. Linear analysis performed using Time History Analysis (THA) for the records of Elcentro earthquake (1940) has been carried out**.** The project has been study to identify the effective of Tuned Liquid Damper(TLD). TLD can be used to control the horizontal vibration in building structures. A Tuned liquid damper is a tank filled with water, TLD is usually placed on the top of the structure nad whenever there is horizontal vibration occurs due to seismic forces that uses the sloshing energy of the water to reduce the effect vibration structure of the system when it is subjected to excitation . Water storage tank designed as to gain its natural frequency same as that of building. As a result the resonant phenomenon will occurs and give contribution to balance the building. A tuned Liquid Damper is a passive control device that dissipates the excitation energy through the boundary layer friction, liquid free surface contamination, and wave breaking.

Keywords - Tuned liquid damper, TLD, seismic protection system, sloshing.

I. INTRODUCTION

Recent earthquakes have highlighted the fragility of existing structures, forcing earthquake engineers to assess the vulnerability of existing structures and work on ways to mitigate the effects of earthquakes on structures. It should be strengthened with the goal of reducing its vulnerabilities. It is critical to research and develop innovative ways for reinforcing and/or improving the performance of structures during earthquakes in order to avoid substantial economic losses and human lives in future disasters. Buildings of rising heights, as well as the use of light-weight materials, high-strength and durable materials, and new construction processes, have resulted in structures that are more flexible and lightly damped. These constructions are, understandably, vulnerable to environmental excitations such as wind, ocean waves, and earthquakes. This causes undesired vibrations, which can lead to structural collapse, occupant discomfort, and equipment malfunction. As a result, it has become important to investigate and seek for new practical and effective technologies for the suppression of vibrations caused by diverse forces.

1.1 Objectives

The goal of this research is to use Etabs 2016 to create an analytical model of a Tuned Liquid Damper and run numerous studies on it. The following are the study's scope and objectives:

1. To review the literature, covering various types of tuned liquid dampers and the behavior of structures constructed with tuned liquid damper
2. Design of Tuned Liquid Damper and model on ETABS 2016
3. Model and analyze the response of an RC structure with a fixed base Without Damper in ETABS 2016
4. Model and analyze the response of an RC structure with a fixed base With TLD Damper in ETABS 2016
5. To study the performance of tuned liquid dampers in earthquake zone IV.
6. To study the vulnerability of with and without TLD models considering different factors such as Storey drift, lateral displacement, story lateral load and base shear for dynamic loading in ETABS 2016 by considering time history analysis for Elcentro.
7. Using TLD, analyse the seismic effect on the structure. TLD is used to evaluate the structure's analytical approach and design requirements..

1.2 Tuned Liquid Damper

TLDs (Tuned Liquid Dampers) have been utilised in a variety of applications, including tall buildings, skyscrapers, and high-rise constructions, as passive control systems. TLDs are passive energy dissipation devices that have been utilised to control structural vibrations under a variety of dynamic loading scenarios. A TLD is made up of a rigid tank that is filled with fluid. This fluid might be water or something else. Sloshing and breaking waves at the resonant frequencies of the combined TLD-structure system are caused by adjusting the Tuned Liquid Damper's fundamental sloshing frequency to the structure's natural frequency, resulting in large quantities of energy dissipation.

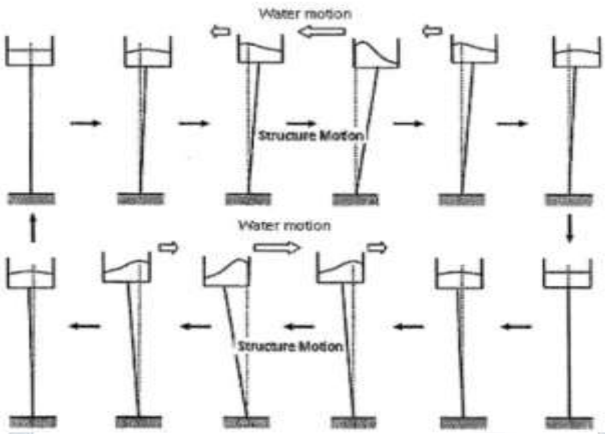


Figure 1.1 Principle of TLD working

1.2.1 TLD behaviour is influenced by a number of factors:

Some parameters that affect the behaviour of TLD, following are:-

1. **Tuning ratio:** Tuning ratio is the ratio of fundamental natural frequency of building to the frequency of TLD, it is seen from the previous researches that the damping effect of TLD is best when the tuning ratio is 1.

2. **Mass ratio**: It is ratio between mass of the TLD to the mass of the structure. The effect of damping increases with the increase in mass ratio..

3. **Depth ratio:** In the direction of sloshing, it is the ratio of the depth of the tank to the length of the tank. The mass of water is split into two parts: convective mass and impulsive mass. The sloshing action is aided by convective mass. The depth ratio is inversely proportional to the ratio of convective mass to impulsive mass of water. As the depth ratio increases, convective mass decreases, and sloshing involvement decreases. As a result, a smaller depth ration is frequently selected.

4. **Shape of tank**: Any tank form may be designed for TLD. It can take the form of a circle, a rectangle, a cone, or any other geometrical shape. However, the form of the tank affects the sloshing behaviour. In general, rectangular or circular tanks are utilised since they are easier to construct than other designs. Because charts are only provided for circular and rectangular tanks in design regulations like IS1893:2002 part 2, rectangle and circular forms are selected for study.

1.2.2 Classification:-

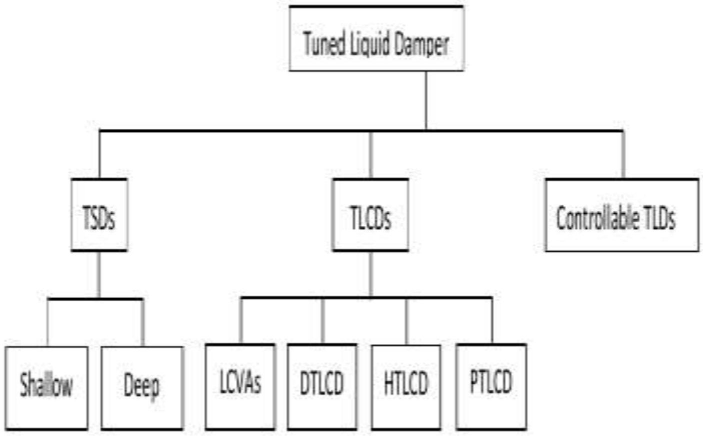


Figure 1.2 Types of Tuned Liquid Damper

TSD: Tuned Sloshing Damper, TLCD: Tuned Liquid Column Damper, LCVA: Liquid Column Vibration Absorbers, DTLCD: Double Tuned Liquid Column Damper, HTLCD: Hybrid Tuned Liquid Column Damper, PTLCD: Pressurized Tuned Liquid Column Damper, ER: Electro Rheological, & MR: Magneto Rheological.

1.2.3 Tuned Sloshing Damper

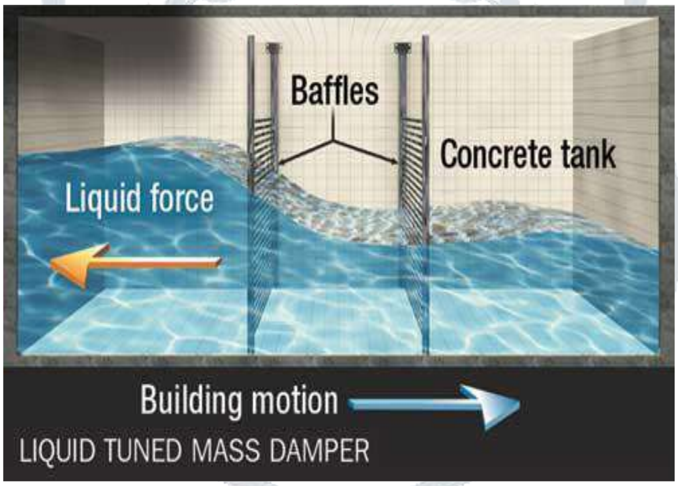


Figure 1.3 Schematic diagram of tuned sloshing damper.

Tuned Sloshing Dampers (TSDs) are generally of rectangular or circular tank partially filled with the liquid such as water or any other suitable fluid. These are generally installed on the terrace of the building with the aim of dissipation of the vibration. TSD can be classified as deep or shallow depending on the depth of fluid. If the depth ratio is less than or equal to 0.15 it can be classified as shallow water type or if the depth ratio is greater than 0.15 it can define as deep water type Fig.1.3 shows the behaviour of liquid during vibration. Depending on the natural frequency of the structure depth of liquid in the tank could be shallow or deep.

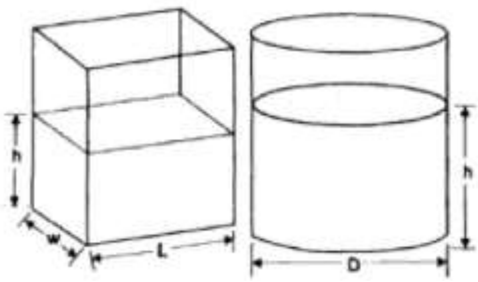


Figure 1.4 (Tuned Liquid Damper Dimensions)

1.2.4 Tuned liquid column dampers

Tuned liquid column dampers (TLCD) is a U-shaped damper, dimensions can be seen in the fig 1.4. When vibration occurs in a tube, the fluid level on both sides fluctuates, resulting in a restoring force produced utilising the liquid's gravity effect, as well as the damping effect induced by the loss of hydraulic pressure. The TLCD can be rectangular or circular in shape and placed on the structure's top surface.

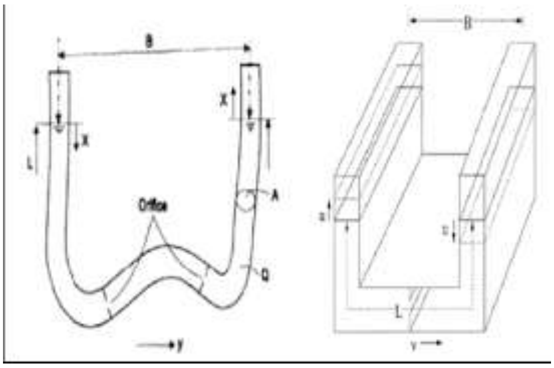


Figure 1.5 Tuned liquid column damper dimensions

II. METHODOLOGY

2.1 Designing the TLD for the structure

In this study case, water is contained in a rectangular tank, with a mass ratio of 3.0 percent. Higher mass ratios were employed in certain research to enhance TLD effectiveness, while other studies indicated that an increase in mass ratio is useful when it is less than or equal to 3%. As a result, a mass ratio of 3.0 percent was used in this investigation, based on the maximum proposed mass ratio for TLDs.

The Procedure for design of the Tuned Liquid Damper is as follows:-

1. The natural frequency of a simple harmonic Pendulum. When calculating the natural frequency, we use the following formula:-

   $$f = \omega \div 2\,\boldsymbol{\pi}$$

   Here, the ω is the angular frequency of the oscillation (radians or seconds). The angular frequency using the following formula:-

   $$\omega = \sqrt{\frac{K}{M}}$$

   By substituting value of ω:-

   $$f = \sqrt{K/M} \div (2\boldsymbol{\pi})$$

   Where,
   M= Mass of the Structure
   K = Total Lateral Stiffness of the Structure
   f = Natural frequency of the structure

2. Natural frequency of water confined in rectangular is find from the following equation , given by (Abramson, 1966)

   $$f = \frac{1}{2\pi}\sqrt{(\frac{\pi g}{L}\tanh\frac{\pi h}{L})}$$

   (Assume h/L = 0.15)

   The fluid's sloshing frequency is equal to the building's first natural frequency.

   where,
   ω = the natural frequency of sloshing in Hz
   h = height of the water in the container
   L= the length of the container in the direction of excitation

Here, the TLD is modelled as a spring mass system as suggested in IS1893:2002 (Part 2) Indian code. The parameters of the TLD is find out from the design curves present in the IS code are used for the design purpose. The steps for design are mentioned below.

Ground supported tanks can be idealized as spring-mass model shown in Fig. The impulsive mass of liquid, *mi* is rigidly attached to tank wall at height *hi* (or *hi*)*. Similarly, convective mass, *mc* is attached to the tank wall at height *c h* (or *hc**) by a spring of stiffness *Kc* .

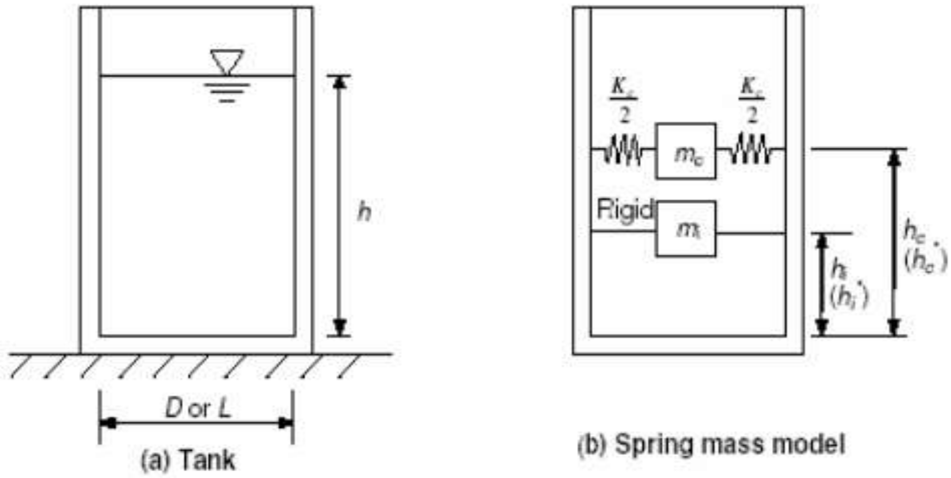


Figure 2.1 Spring mass modal for ground support circular and rectangular tank as per IS-Code 1893 (Part II)

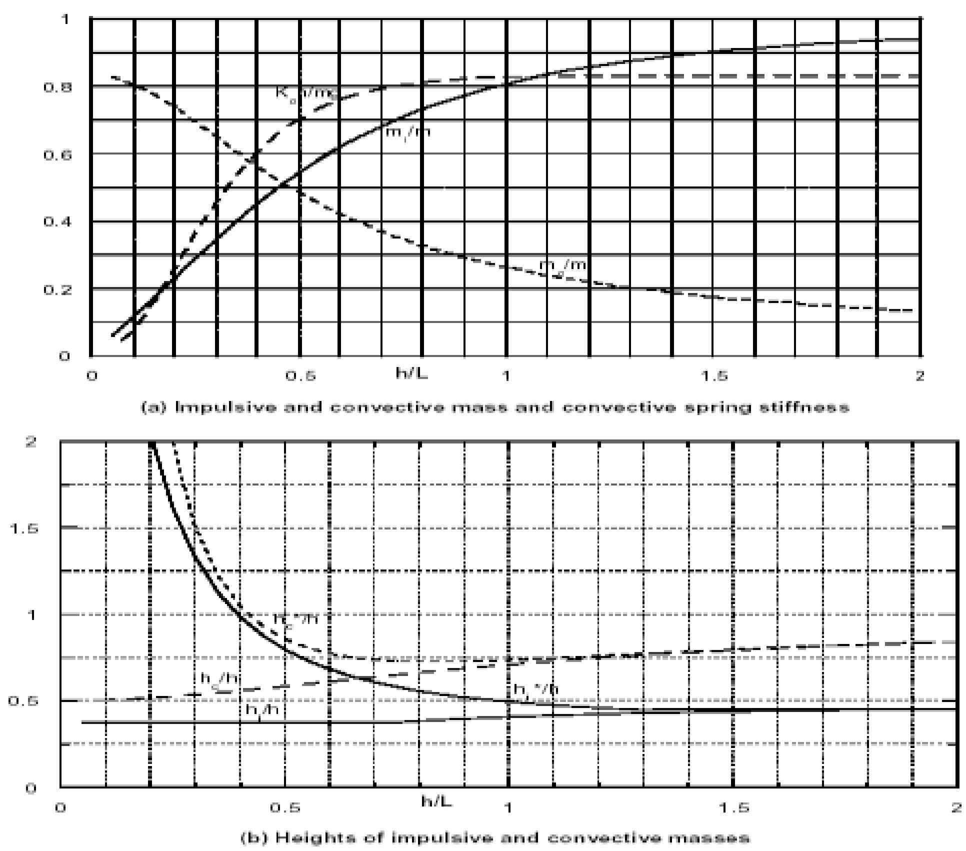


Figure 3.2 Parameters of the spring mass modal for rectangular tank as per IS Code 1893 (Part II)

2.2 Using IS 1893:2002 part 2 curves:-

For elevated tanks with rectangular container, parameters *mi*, *mc*, *hi*, *hi*, *hc h*c* and *Kc* shall be obtained from Fig. 3.3 corresponding to given *h* / *D ratio*.

M = Mass of the structure
m = Mass of the damper
mc =active/convective mass of water in the tank
mi = inactive/ impulsive mass of water in the tank
Kc = spring stiffness of convective mode

hc = Height of convective mass above bottom of tank wall
hi = Height of impulsive mass above bottom of tank wall

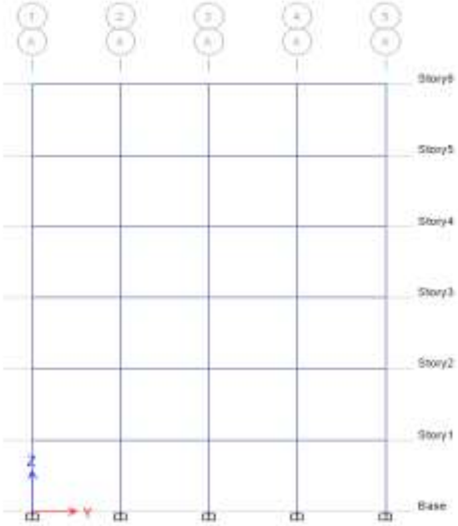
2.3 Design & modelling of tuned liquid damper

Table 2.1: Member Properties & Specifications for the Models Sizes of the member are as follows:

Type of Structure	**Ordinary Moment-Resisting Frame**
Type of building	Residential Apartment
Load Combination	According to IS : 1893 (Part 1) :2002
Total area of building	16*16 = 256m^2
Number of floors	G+5
Total height of the building	18m
Floor to floor height	3.5m
Grade of concrete	M25
Grade of steel	Fe415
Thickness of slab	150mm
Size of column	300mmX500mm
Size of beam	300mmX450mm
Live load	3KN/m^2
Density of concrete	25KN/m^3
Response reduction factor	3
Importance factor	1
Site located in Seismic zone 5	Z- 0.36
Soil type	Medium
Floor Finish	1 kN/m^2
Mass Source	DL + (0.25 x LL)
No. of the bay in X direction	5
No. of the bay in Y direction	5
Bay width	4m

Table 2.2 Parameters of TLD

Mass of damper	39892.981 Kg
Convective mass of damper	3017.90 Kg
Impulsive mass of damper	9574.075 Kg
Height of convective mass	0.1635 m
Height of Impulsive mass	0.1226 m



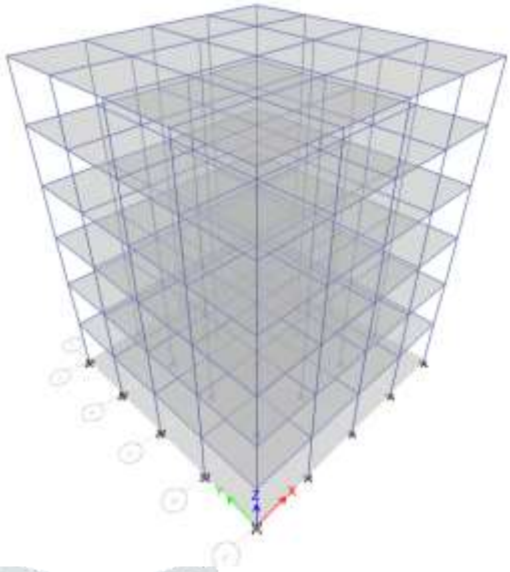


Fig 2.2 Elevation view of G+ 5 Residential building model **Figure 2.3** Isometric view of G+ 5 Residential building model

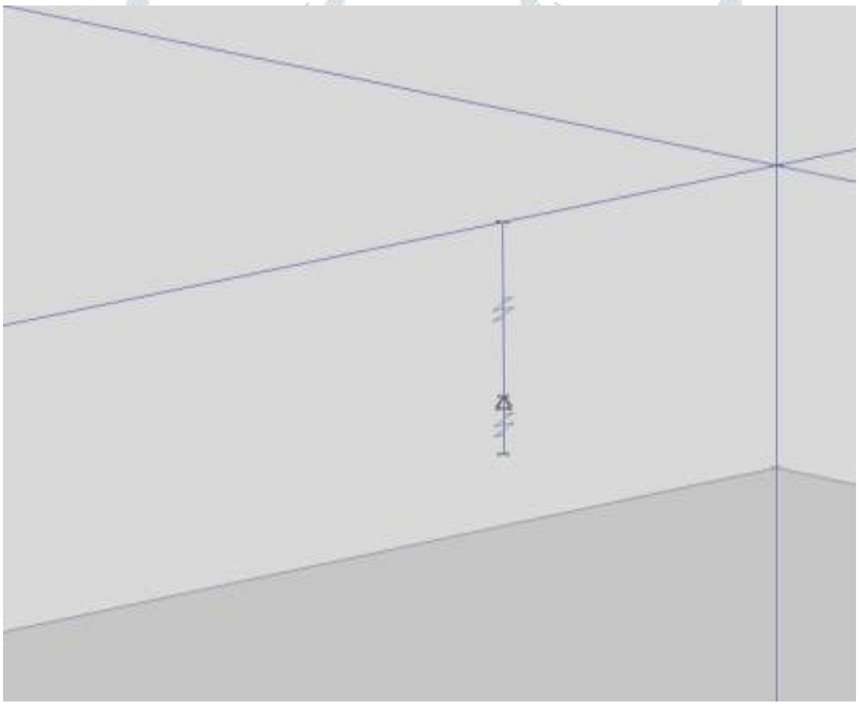


Figure 2.4 Arrangement of Tuned Liquid Damper

III. RESULTS

3.1 Story displacement

Displacements of different stories were determined using Time History Analysis in x and y direction for building without damper and building with tuned Liquid damper. Tables and graphs are shown to determine the efficiency of damper and reduction in response.

Table 3.1 Displacement from time history analysis in x direction due to EX

Story	Elevation m	Without TLD mm	With TLD mm
Story6	21	29.022	0.464
Story5	17.5	26.467	3.648
Story4	14	22.177	5.196
Story3	10.5	16.674	4.873
Story2	7	10.515	3.405
Story1	3.5	4.293	1.455

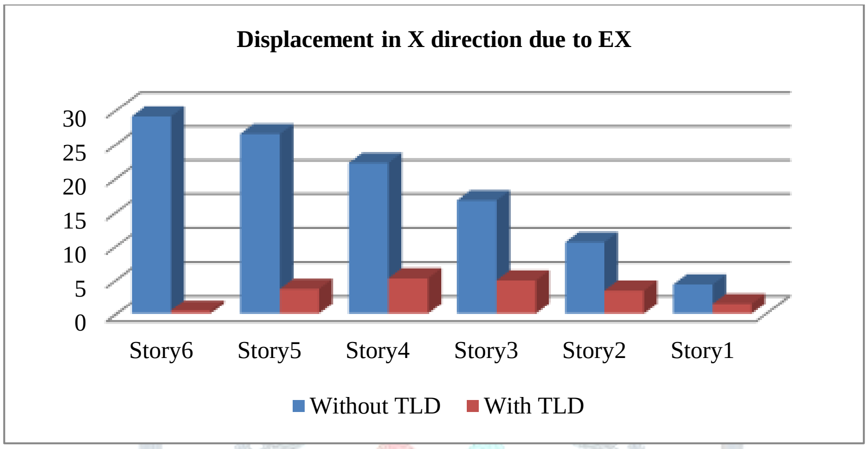


Fig 4.1 Story displacement in x direction due to EX

Table 3.2: Displacement from time history analysis in y direction due to EY

Story	Elevation m	Without TLD mm	With TLD mm
Story6	21	39.709	0.687
Story5	17.5	36.857	6.955
Story4	14	31.845	9.525
Story3	10.5	25.395	8.859
Story2	7	18.141	6.315
Story1	3.5	10.382	2.932

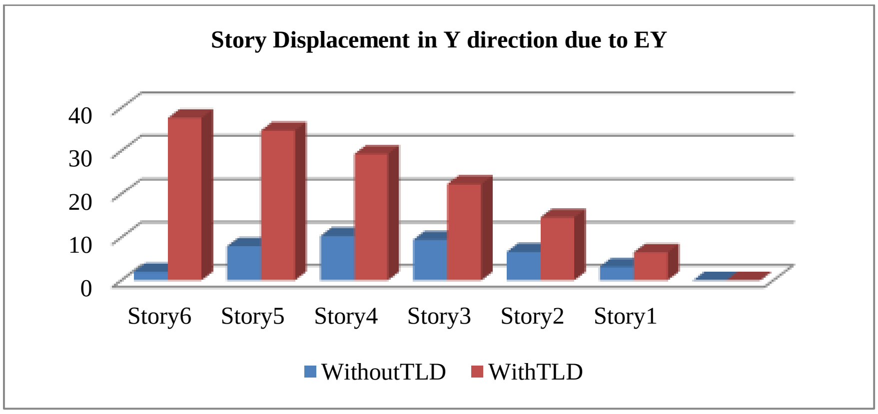


Fig 3.2 Story displacement in y direction due to EY

3.2 Story Stiffness

Stiffness of different stories were determined using Time History Analysis in x and y direction for building without damper and building with tuned liquid damper Tables and graphs are shown to determine the efficiency of damper and reduction in response.

Table 3.3 Stiffness from time history analysis in x direction

Story	Elevation m	Without Damper KN/m	With TLD KN/m
Story 6	21	173771.062	264068.175
Story 5	17.5	192677.263	180437.174
Story 4	14	194593.087	338221.889
Story 3	10.5	196257.847	222698.636
Story 2	7	203974.86	217240.543
Story 1	3.5	299581.718	308143.729

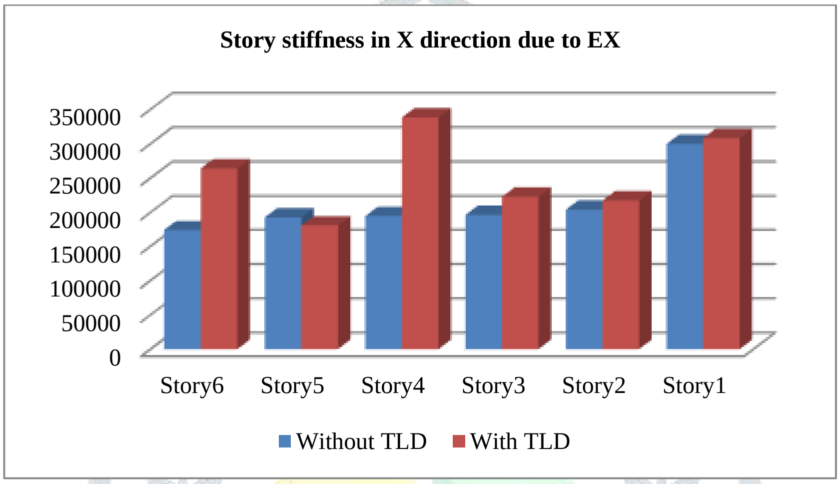


Fig 3.3 Story Stiffness in x direction

Table 3.4 Stiffness from time history analysis in y direction

Story	Elevation	Without Damper KN/m	With TLD KN/m
Story 6	21	109227.506	141424.739
Story 5	17.5	115642.325	109221.768
Story 4	14	116463.768	158970.634
Story 3	10.5	117083.153	125878.835
Story 2	7	118624.741	122893.601
Story 1	3.5	147805.743	149868.057

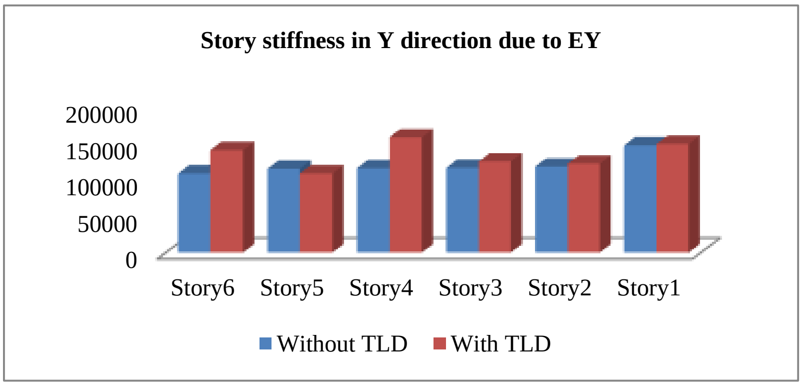


Fig 3.4 Story Stiffness in y direction

3.3 Story Overturning Moments:-

Overturning Moments of different stories were determined using Time History Analysis for building without damper and building with tuned liquid damper. Tables and graphs are shown to determine the efficiency of damper and reduction in response.

Table 3.5 Overturning Moments of building from time history analysis

Story	Elevation m	Without Damper KN-m	With TLD KN-m
Story 6	21	-0.0037	-0.0024
Story 5	17.5	-0.6304	0.029
Story 4	14	-1.9823	0.0175
Story 3	10.5	-3.9673	-0.0354
Story 2	7	-6.453	-0.1233
Story 1	3.5	-9.2751	-0.2359

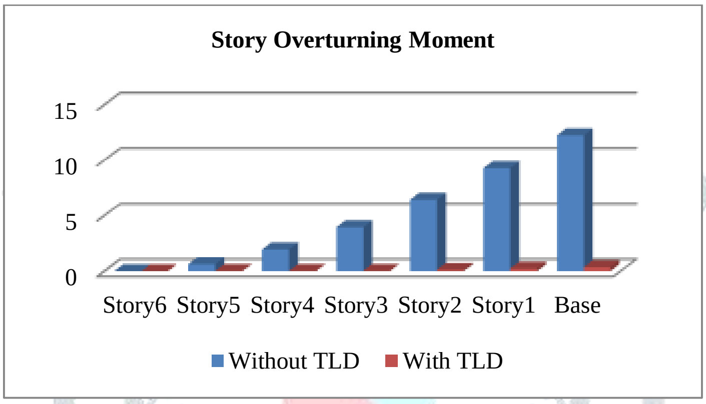


Figure 3.5 Story Overturning Moments

3.4 Story Drift

Drift of different stories were determined using Time History Analysis in x and y direction for building without damper and building with tuned liquid damper. Tables and graphs are shown to determine the efficiency of damper and reduction in response.

Table 3.6: Drift from time history analysis in x direction due to EX

Story	Elevation (m)	Without Damper	With TLD
Story 6	21	0.00073	0.00101
Story 5	17.5	0.001226	0.000443
Story 4	14	0.001573	9.20E-05
Story 3	10.5	0.00176	0.000419
Story 2	7	0.001779	0.000557
Story 1	3.5	0.001227	0.000416

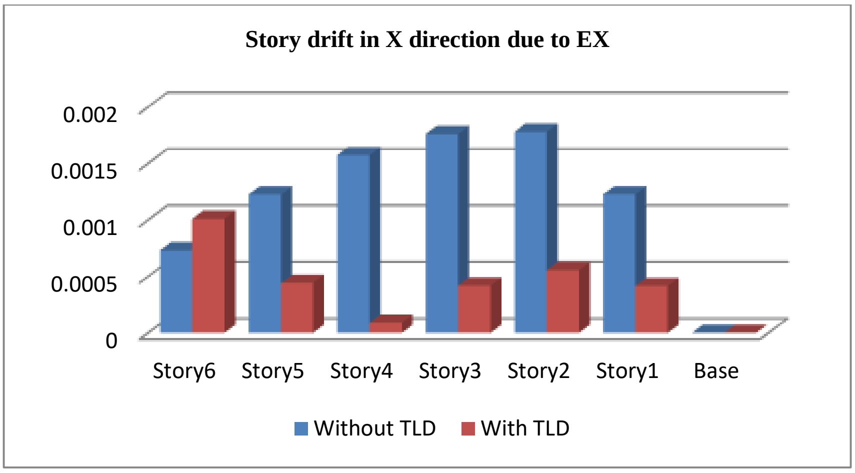


Figure 3.6 Story Drift in x direction

Table 3.7: Drift from time history analysis in y direction due to EY

Story	Elevation m	Without Damper	With TLD
Story 6	21	0.000874	0.001882
Story 5	17.5	0.001537	0.000823
Story 4	14	0.001978	0.000251
Story 3	10.5	0.00222	0.00079
Story 2	7	0.002302	0.00103
Story 1	3.5	0.00187	0.000883

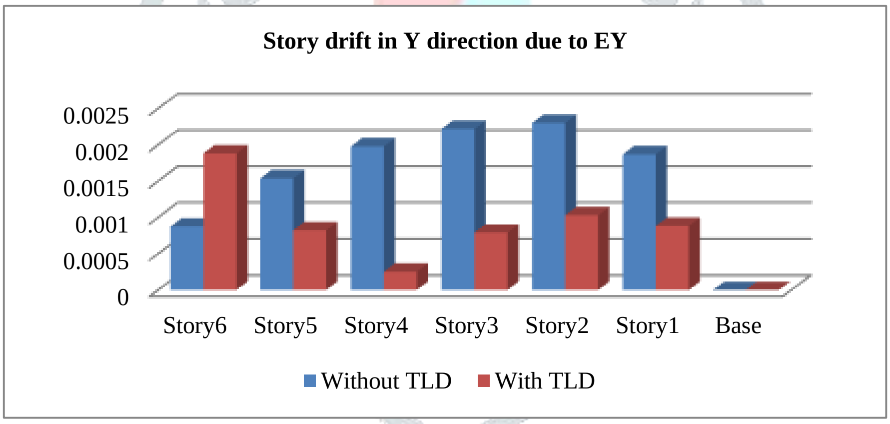


Figure 3.7 Story Drift in y direction

3.5 Story Lateral Loads

Lateral load of different stories were determined using Time History Analysis for building without damper and building with tuned liquid. Tables and graphs are shown to determine the efficiency of damper and reduction in response.

Table 3.8: Lateral load from time history analysis in x direction due to EX

Story	Elevation m	Without Damper KN	With TLD KN
Story 6	21	443.7162	789.0327
Story 5	17.5	382.4169	606.2655
Story 4	14	244.7468	388.0099
Story 3	10.5	137.6701	218.2556
Story 2	7	61.1867	97.0025
Story 1	3.5	15.2967	24.2506

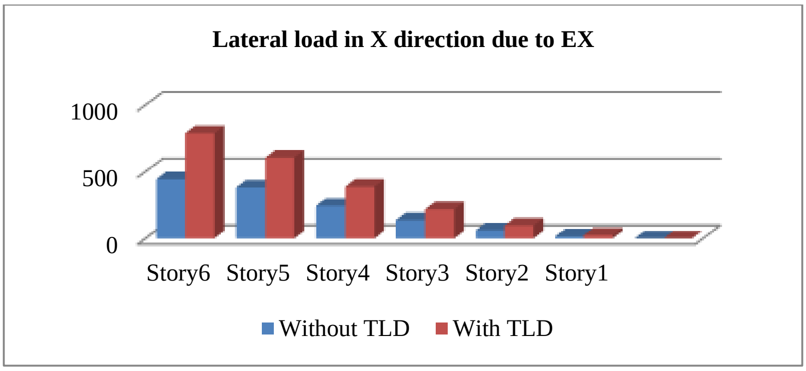


Fig 3.8 Lateral load in x direction

Table 3.9 Lateral from time history analysis in y direction due to EY

Story	Elevation m	Without Damper KN	With TLD KN
Story 6	21	333.9852	784.5343
Story 5	17.5	287.8452	602.8091
Story 4	14	184.2209	385.7978
Story 3	10.5	103.6243	217.0113
Story 2	7	46.0552	96.4495
Story 1	3.5	11.5138	24.1124

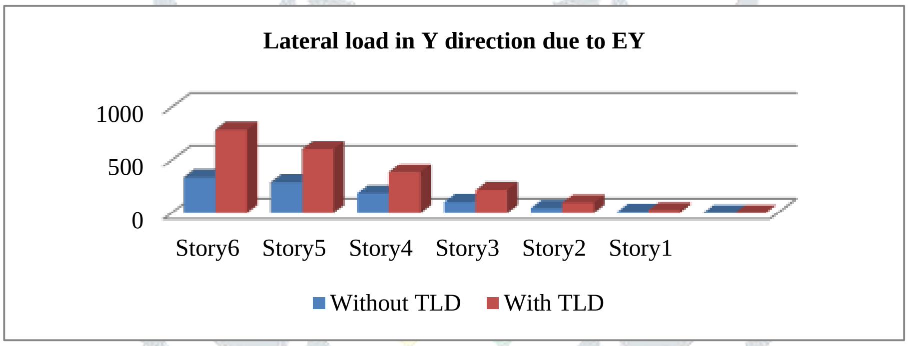


Fig 3.9 Lateral load in y direction

3.6 Base Shear

Base Shear of building was determined using Time History Analysis in x and y direction for building without damper and building with tuned liquid damper. Tables and graphs are shown to determine the efficiency of damper and reduction in response.

Table 3.10: Base Shear from time history analysis in x and y direction

Direction	Without Damper KN	With TLD KN
x	1169.0592	2117.662
y	899.8672	2101.4718

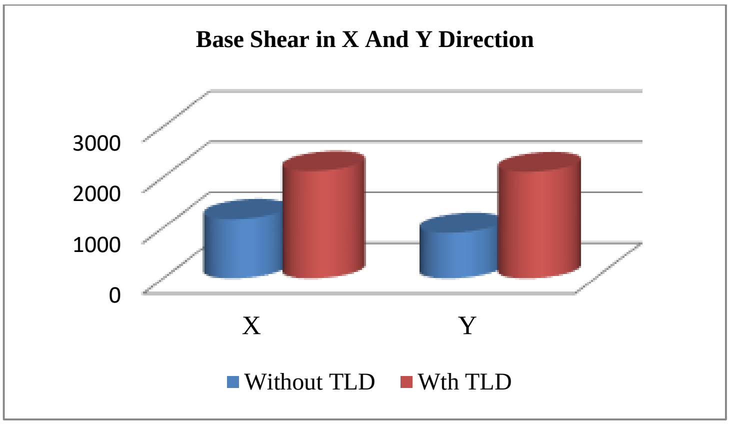


Fig 3.10 Base Shear in x and y direction

VI. CONCLUSION AND FUTURE SCOPE

4.1 Conclusion

1. The mass ratio and the depth ratio are TLD parameters that have considerable effect of the ability of a TLD to control structural response to large amplitude base excitations. A 3% mass ratio and 0.15 depth ratios are found to be effective for TLD

2. TLD considered as the reliable for the earthquake resistance design, this ensures the protection of structural as well as non-structural elements and minimize the losses of living and non-living beings, thereby keeping the building operational even after a severe earthquake.

3. There is also an advantage of using TLD i.e. instead of using a huge mass (TMD), it easy to install, low cost and also water can also utilize during fire hazards, and also required lesser area consumed by the damper.

4. In this work by using TLD story displacement on top story is reduced by 97-98 %, that means story displacement is comparatively very when using TLD, also the maximum displacement reduce by 82% in X-direction due to EX and 76% in Y-direction due to EY.

5. Story drifts decreases with the application of dampers and result to more stable structure.

6. Lateral loads with the dampers are comparatively increases as compared to without damper in every floor.

According to the findings, a traditional TLD was able to reduce structural vibrations in a vertically regular building. The tuning frequency and placement of TLDs were also shown to have a substantial impact on the efficiency of structural vibration reduction. It should be noted that the experimental findings achieved from this work are dependent not only on the TLD properties used, but also on the test structure's modal displacement. As a consequence, additional research is required to synthesise the findings of this study.

5.2 Future Scope for Study:

1. To achieve different control performance, the research may be expanded by inserting obstacles such as baffles, screens, and floating particles in the tank.
2. The research may be expanded to look at the impact of other tank geometries, such as the shape of the tank and the type of tank bottom.
3. Analyses will be carried out on irregular structures with varying soil conditions.
4. The study further can carried out by installing TLD at different location in building.
5. The study further can carried out with different width and depth dimensions of water tank.
3. This study done by assuming 3% mass ratio, the further study can be done by using different mass ratio.
4. The study can be further carried out with infill wall.

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