SEISMIC ANALYSIS OF HIGH-RISE BUILDING USING TUNED LIQUID COLUMN DAMPER

A DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR

THE AWARD OF THE DEGREE

OF

MASTER OF TECHNOLOGY

IN

STRUCTURAL ENGINEERING

Submitted by

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I, **Prashant**, Roll No.**2K19/STE/22** of MTech (Department of Civil Engineering), hereby declare that the project Dissertation titled "**SEISMIC ANALYSIS OF HIGH-RISE BUILDING USING TUNED LIQUID COLUMN DAMPER**" which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of degree of Masterof Technology in Structural Engineering, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associate ship, Fellowship or other similar title or recognition.

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CERTIFICATE

I, hereby certify that the Project Dissertation titled "**SEISMIC ANALYSIS OF HIGH-RISE BUILDING USING TUNED LIQUID COLUMN DAMPER**" which is submitted by **Prashant**, Roll No. **2K19/STE/22** (Department of Civil Engineering), Delhi Technological University, Delhi in partial fulfilment of the requirementfor the award of the Degree of Master of Technology, is a record of the project carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any degree or diploma to this University or elsewhere.

31.05.2022

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ACKNOWLEDGEMENT

"It is not possible to work upon a project without the assistance & encouragement of other people. This one is certainly no exception."

On the very outset of this dissertation, I would like to extend my sincere & heartfelt obligation towards all the personages who have helped me in this endeavour. Without their active guidance, help, cooperation & encouragement, I would not have made headway in the project. I take the privilege to extend my hearty thanks to my supervisor Associate Professor G.P. Awadhiya , Civil Engineering Department for his for conscientious guidance and encouragement to accomplish this project.

I extend my gratitude to Delhi Technological University for giving me this opportunity. I also acknowledge with a deep sense of reverence, my gratitude towards my parents and member of my family, who has always supported me morally as well as economically.

At last, but not least gratitude goes to all of my friends who directly or indirectly helped me to complete this project report. Any omission in this brief acknowledgement does not mean lack of gratitude.

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ABSTRACT

Current trends in the construction sector demand higher, lighter buildings that are also more flexible and have a low damping value. There are a few procedures available these days to restrict the vibration of a structure; among the few options to control vibration, the idea of using TLD and TLCD is a recent one. The objective of this study is to see whether Tuned Liquid Column Dampers (TLCD) can reduce seismic vibration in a structure when it is subjected to horizontal excitation. In this study, an approach for designing TLCD for a structure has been suggested, as well as a strategy for demonstrating TLCD in the ETABS 2019 software.

In the present work of G+12, G+17, G+20, G+24 story buildings, it is analyzed by using a time history function with and without TLCD (as a TMD). And response of the building as a maximum story displacement, and story drift etc. can be obtained by using the tool like ETABS 2019. A tuned mass damper (TMD) is a equipment that is connected to a structure and consists of a mass and a spring to minimize the structure's dynamic response.

In time history analysis, mainly El-Centro earthquake used which is presented in this work using ETABS 2019 software.

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CHAPTER 1

INTRODUCTION

1.1 Background:

Seismic analysis is a part of structural analysis that involves evaluating the response of a structure when it has been subjected to seismic excitation. In earthquake-prone regions, that's also important for structural design and evaluation, and retrofitting of structures.

Currently, the number of tall structures that are highly flexible and have a very low damping value is increasing in order to reduce the growing space constraints in metropolitan areas. Various approaches have been used to build the structures free from earthquake as well as wind-induced structural vibrations, which may be generally divided into four groups:

(a) Active control, (b) Passive control, (c) Semi-active control and (d) Hybrid control.

1.1.1 Active control devices:

Control actuators are used in these devices to impart forces to the structures using an external power source. Various signals are provided to these actuators as a result of the structures reactions. To mention a few active control devices, there are active tuned mass dampers, active tuned liquid column dampers, and active variable stiffness dampers. Applications - Trigon on Shinjuku Tower, AMD on Kyobashi Seiwa Building, Nighikicho.

1.1.2 Passive control devices:

It's a device that transmits forces produced in reaction to the movement of structures. It reduces the structure's energy dissipation demand by absorbing some of the incoming energy. As a result, adding energy to the structural system does not necessitate the use of an external power source. Passive control devices include base isolation, tuned mass dampers (TMD), tuned liquid dampers (TLD), viscous fluid dampers, and metallic yield dampers. Applications - USC Teaching Hospital in Los Angeles, NZ Parliament Building and the associated Assembly Library, Matsumura Research Institute building in Kobe, City halls of Oakland, USC Teaching Hospital in Los Angeles.

1.1.3 Semi-active control devices:

Those are the customizable passive control system with a lower external energy need than active devices. It brings together positive elements of active and passive control systems. These devices create forces as a consequence of structure's motion, but they can't provide energy to the system. Variable orifice dampers, variable friction dampers, variable stiffness dampers, and adjustable fluid dampers are all examples of semi-active control devices.

Applications- Keio University, Science and Technology Tokyo in Japan, Kajima Shizuoka Building in Shizuoka, Japan, 11-storey building CEPCO Gifu Japan.

1.1.4 Hybrid control Devices:

To reach a better degree of performance, these devices integrate passive, active, or semi-active components. Less active control effort is required since passive system achieves an amount of control aim, indicating a lower power resource.

Applications- Sendagaya INTES building in Tokyo

With rapid economic efficiency and sustainable technology, civil infrastructures such as tall structures and long span bridges are constructed with more flexibility, increasing their vulnerability to external excitation. Designing tall structures is becoming common in recent years in order to reduce the growing space constraints in metropolitan areas. These constructions are typically built light and flexible, with little damping, resulting in a structure that is more vibration prone. However, it may have the potential to ruin the cladding and partitions, as well as cause service difficulties, in addition to increasing the chance of different failures. As a result, it is critical to keep the frequency of objectionable motion below a certain threshold in order to assure that highrise buildings work effectively. Several approaches to achieving this goal **[1]** are presented below.

Means	Type	Methods	Remarks
Auxiliary Damping device	Passive	Energy-dissipating materials are added, Increasing building damping ratio	SD, SJD, LD, FD, VED, VD, OD
		Adding an additional mass system to raise the damping level	TMD, TLD
	Active	Applying inertia effects to generate control force in order to minimize response	AMD, AGS
		Applying aerodynamic control force to reduce wing force coefficient or decrease response	Rotor jet, Aerodynamic Appendages
		Varied stiffness to avoid resonance	AVS

Table 1. 1 Different types of methods

SD: Steel dampers, SJD: Steel Joint dampers, LD: Lead dampers, FD: Friction Dampers, VED: Visco-Elastic Dampers, VD: Viscous Dampers, OD: Oil Dampers, TMD: Tuned Mass Dampers, TLD: Tuned Liquid Dampers, AMD: Active Mass Damper, AGS: Active Gyro Stabilizer, AVS: Active Variable Stiffness,

Along with certain significant advantages, each of these techniques has its own set of limitations and drawbacks. However, the use of Tuned Liquid Dampers (TLDs), which include both TSDs and TLCDs (Tuned Sloshing Dampers and Tuned Liquid Column Dampers), is growing rapidly as a realistic structural control solution.

Dampers have been employed in anti-rolling tanks since the 1950, counteract rocking and rolling vibrations in marine vessels. In 1960, Nutation Dampers, which are used to regulate a satellite's wobbling motion in orbit, were invented using the same technique. However, in the mid of 1980s by Bauer **[2]**, who recommended filling a rectangular container with two immiscible liquids entirely to decrease structural reaction to dynamic loading, the idea of using TLDs to reduce structural vibration in civil engineering structures was developed. Fujii **[3]** , Kareem **[4]** , were also among the first to propose the use of liquid-motion dampers in civil engineering constructions. All of these dampers worked on the concept of liquid sloshing, which is why they're sometimes termed Tuned Sloshing Dampers (TSDs).

Over the previous two decades, many different forms of liquid dampers have been presented, with the Tuned Liquid Column Damper (TLCDs) being the most well-known. By dispersing energy by the motion of liquid mass in a tube-like container with orifices, TLCDs reduce wind and earthquake caused motion.

1.2 Classification of TLD (Tuned Liquid Damper):

Tuned liquid dampers (TLDs) are classified mainly into three types and may be used both as an active or passive device, as shown in figure below:

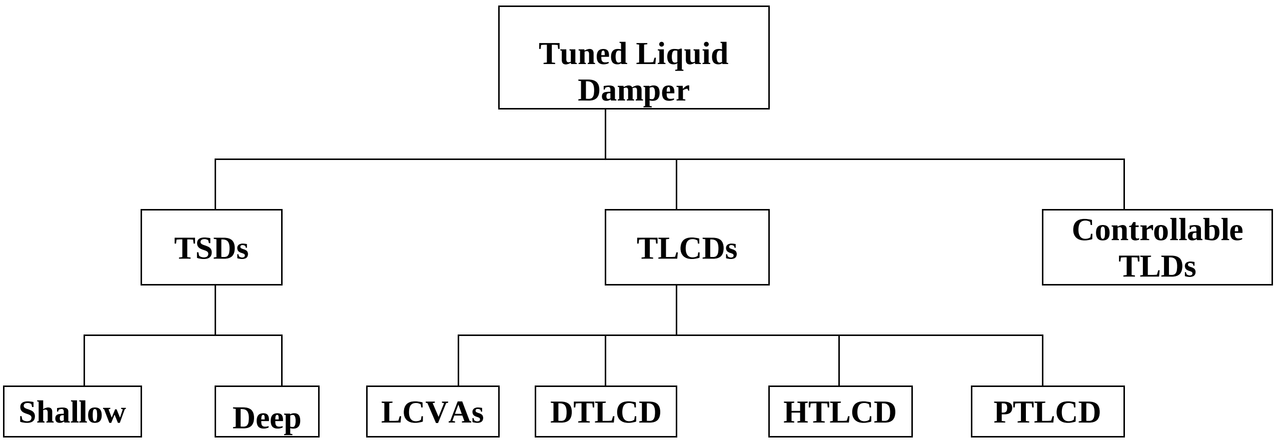


Figure1. 1 Diagram of Tuned Liquid Damper family

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.

Advantages of Tuned Liquid Damper:

TLD has numerous benefits over conventional damping systems as a passive energy dissipation device, which include:

(a) Installation and RMO (Running, Maintenance, and Operation) costs are low.
(b) There are fewer mechanical issues because there are no moving parts.
(c) It is easy to install in both new and existing structures since it is not dependent on the installation site.
(d) It can also be used to regulate several types of vibration in a several degree of freedom , each of which has its distinct frequency.
(e) Non restriction to unidirectional vibration.
(f) Adjusting the depth of liquid and container size can regulate the natural frequency of TLD.
(g) The water inside the damper can be utilised to extinguish a fire.
(h) Applicable to temporary use.

TLD behaviour can be influenced by a variety of factors.

TLD's actions in building are influenced by a number of factors. Natural building frequency, excitation frequency ratio, tuning frequency ratio depth ratio, mass ratio, tank geometry, and tank location at the building are only a few of them. Here is a list of all of them.

(a) Tuning ratio: The tuning ratio is the proportion between the TLD and the building frequencies. When the tuning ratio is 1, the dampening effect of T LD is maximum, and it is known to reduce significantly as the tuning ratio approaches unity.

(b) Mass ratio: The mass ratio is a measure of a TLD's liquid mass to the entire mass of the structure. The impact of damping increases in perfect agreement with the mass ratio shift. Because the TLD is accumulating weight, it will have a greater damping or sloshing effect to offset the earthquake's intensity.

(c) Depth ratio: In the sloshing direction, the depth ratio is the ratio of tank depth to tank length. Convective mass and impulsive mass are two types of water mass, with convective mass being involved in the sloshing process. As a result, a smaller depth ratio is always desired.

(d) Position of tank: TLD behaviour is also influenced by the tank's location. TLD can be placed anywhere in the building, from middle to the top. It might also be situated in the centre, edge, or corner of the storey. TLD has the best effect when placed on the terrace, according to the majority of literature.

1.2.1 Tuned Sloshing Damper:

Tuned Sloshing Dampers are circular or rectangular dampers installed on a structure's highest floor, depending on the kind of construction and the vibration control purpose **[4] [5] [6].** Depending on the height of the water in the tank, TSD is divided into two categories: shallow water as well as deep water. The shallow water wave theory supports this categorization of TSDs**.** If the height of the water "h" is less than 0.15 in proportion to the length of a water tank in the direction of excitation "L" (or dia. "D" for a circular tank), the water type is shallow; if it is higher than 0.15, the water type is deep. The schematic of a TSD is shown in Fig. 1.2. The depth or shallowness of the liquid in a container depends on the inherent frequency of the structure under control. Shallow water has a severe damping effect, for a short level externally

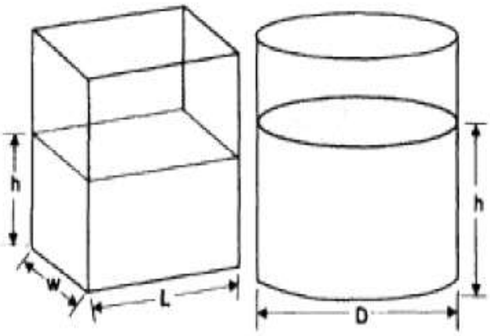


Figure1. 2 Tuned Liquid Damper Dimensions

generated vibration, however, due to the nonlinear behaviour of sloshing water in a tank, evaluating the system for a large scale of externally induced vibration is quite difficult. For a large scale of externally produced force, the sloshing in deep water displays linear **[7].**

Large sloshing amplitudes can be predicted when the tank motion frequency is near to one of the inherent frequencies of the tank fluid. Resonances will develop if both frequencies are fairly near to one other. Tuning the TLD's basic sloshing frequency to that of structure's natural frequency generates a substantial quantity of sloshing and wave breaking at the combined TLD-Structure system's resonant frequencies, dissipating a significant amount of energy **[8].**

1.2.2 Tuned Liquid Column Damper:

The restoring force is due to gravity acting on the liquid, and the damping effect is due to the loss of hydraulic pressure related to the orifice. TLCDs absorb structural vibration by a composite action that involves movement of the liquid mass in the tube. The layout of a TLCD is shown in Fig. 1.3. **[9]**.

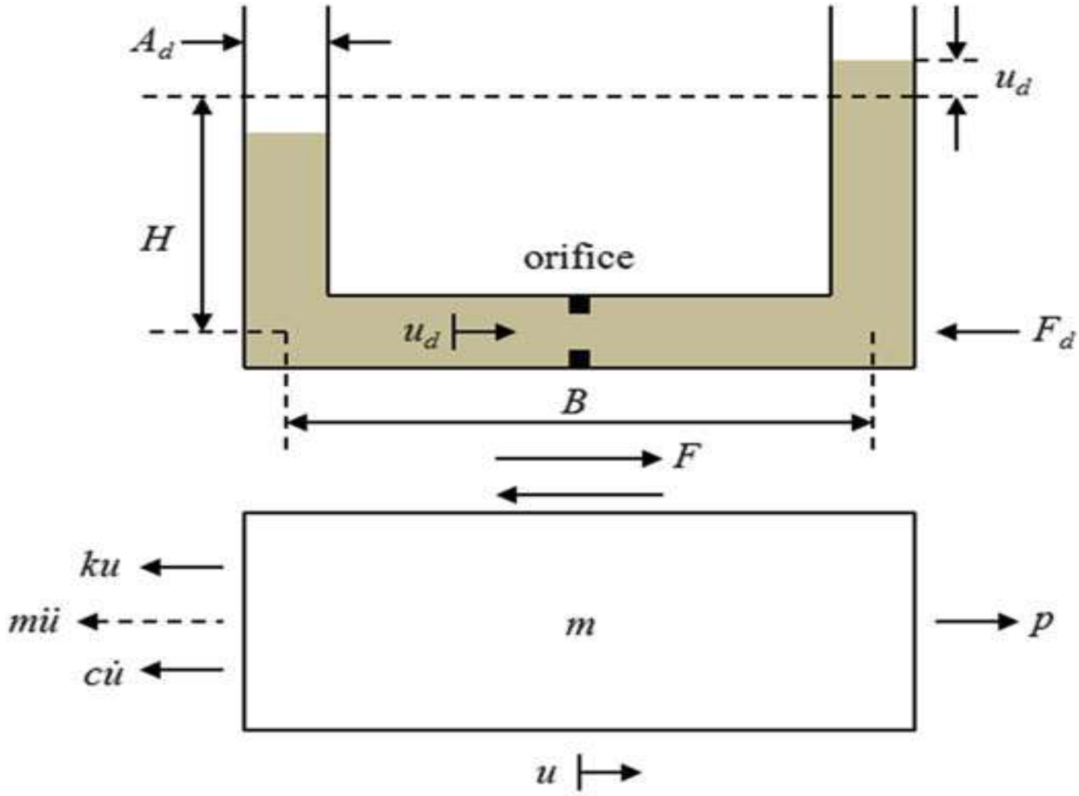


Figure1. 3 (Tuned Liquid Column Damper Dimensions)

The TLCD has certain a number of benefits over other damping mechanisms, including TSDs, as a damper system:

(a) TLCD may assume any arbitrary shape and can be simply integrated into an existing structure.

(b) Unlike TSDs, the mechanism of TLCD is fully understood, allowing for the formulation of a precise model that precisely describes the TLCD's dynamics.

(c) We can regulate the damping performance of the TLCD by adjusting the orifice opening. As a result, we may actively regulate the damping in the TLCD system.

(d) By adjusting the liquid column in the tube, we can modify the frequency of a TLCD.

There is one primary drawbacks of the TLCD and LCVA systems is their unidirectional operation, which means they can only be used on structures that oscillate in one prevailing plane. They cannot be used on structures that oscillate in two planes. A system known as the Double Tuned Liquid Column Damper (DTLCD) has been proposed to overcome this issue, which consists of two TLCD in orthogonal orientations. The schematic of a DTLCD is shown in Fig. 1.4. (Next Page)

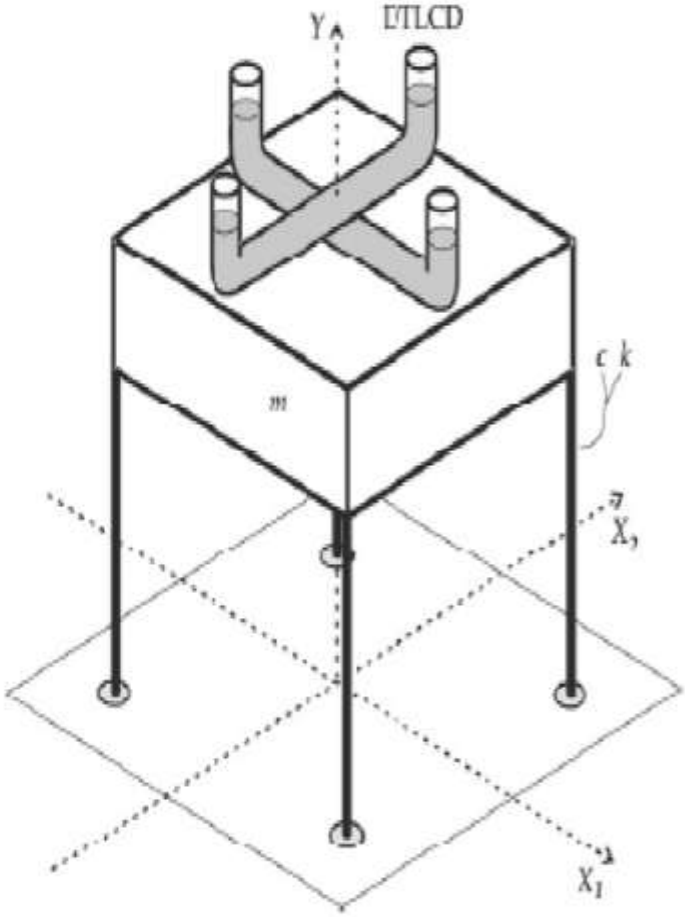


Figure1. 4 A Double Tuned Liquid Column Damper

To solve the problem, the Hybrid Tuned Liquid Column Damper (HTLCD) is a hybrid fluid dynamic system that has been designed **[10].** In this system, a unidirectional TLCD is installed on bottom surface of a revolving circular platform, which can be moved by an electrical-mechanical system. In terms of providing control force to reduce displacement amplitudes, this hybrid system is passive, but active in terms of identifying the right direction. The schematic of an HTLCD is shown in Figure 1.5.

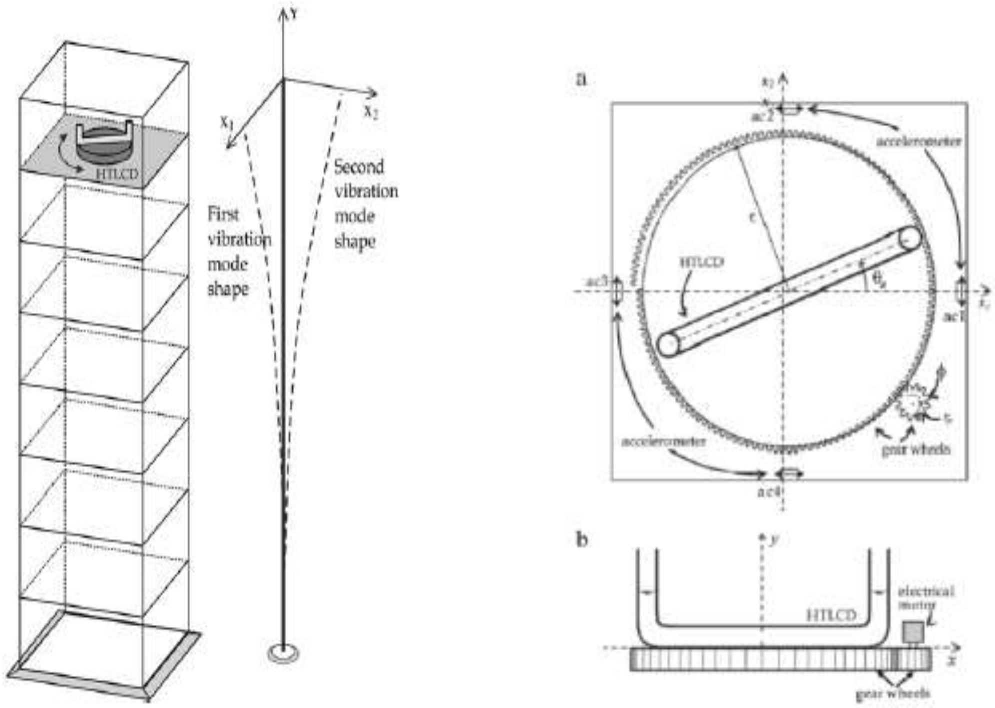


Figure1. 5 A Hybrid Tuned Liquid Column Damper

1.3 Tuned mass damper:

It is defined as a passive control device that lowers the structures dynamic response by attaching itself to it as a secondary mass while increasing damping capacity. It's been widely applied for vibration control in mechanical engineering applications. To achieve optimum responsiveness, the secondary mass's natural frequency is constantly tuned to the main structure's frequency, so that when the structure's frequency is stimulated, the structure's frequency is stimulated as well, the TMD's resonant frequency will be out of phase with the structural vibration. The structure's additional energy is transformed into secondary mass and released as a result of relative motion produced between them later.

1.4 Practical Implementation:

“One wall centre (Sheraton Vancouver Wall Centre Hotel), a 48-story hotel in Canada, is equipped with a tuned water damper at the building's highest point, consisting of two water tanks that are meant to counterbalance the building's harmonic frequency

Figure1. 6 One Wall Centre

U-shape TLCDs are one of the most popular types of liquid dampers. They dissipate vibration energy using the oscillation of water from one column of the U-shape structure to the other column while passing through an orifice at the base (see Fig. 1.8). Figure 1.3 shows One Wall Centre, a 48-story building located in Vancouver, British Columbia. The building has a slenderness ratio of 7:1. Two tuned liquid column dampers containing 60,000 US gallons of water (230 tons) were installed to mitigate vibrations due to wind. The dampers were tuned to the fundamental frequency of the structure” **[9].**

Till date, it was initially installed at the Nagasaki Airport Tower, which is 42 metres tall, in Nagasaki, Japan, in 1987 **[11] ,** Tuned liquid dampers installed in a variety of structures throughout the world, firstly as a strictly temporary installation to evaluate the TLD's effectiveness in decreasing structural vibration. The exact measurements were a bit of a warning. The installation of 25 TLD vessels resulted in a 44 percent reduction in vibration amplitude (from 0.79 mm without TLD to 0.44 mm), as well as a 35 percent reduction in RMS displacement.

TMD also implemented in two buildings of the US. The Citicorp Centre in the New York City is one of them, which is 279 metres tall and is located on the 63rd floor, at the structure's highest point, the building's amplitude was reduced by 50% .

CHAPTER 2

LITERATURE REVIEW

2.1 General

A tuned mass damper (TMD) is a mechanism that is attached to a structure and consists of a mass, a spring, and a damper. Its purpose is to minimize the structure's dynamic response. The damper's frequency is matched to the structural frequency when it is stimulated, causing the damper to resonate out of phase with the structural motion. The damper inertia force on the structure dissipates the energy. In 1911, Frahm applied the TMD concept to reduce ship rolling motion and hull vibrations for the first time. Later in the research, Ormondroyd and Den Hartog presented an explanation for the TMD **[9].** Among the many seismic response control technologies, TMD has proven to be successful in decreasing seismic response. Passive TMD is a framework that is spring-attached to the main framework and has a TMD parameter that is matched to that of the main structure, reducing the main structure's dynamic reaction during an earthquake. Instead of connecting a specific element to the main structure. The water tank (TLDs or TLCDs) may be used as a passive TMD because it is an integral part of the structure. TLD is a passive damper that absorbs and dissipates vibration energy by using the motion of a shallow liquid in a container. Both TLD and TLCD provides a number of possible benefits over TMD. Relatively low cost, simple installation, and low maintenance are just a few of TLD's benefits. Both are also more effective than TMD at suppressing small amplitude vibrations over a broad range of stimulation frequencies. The TLD and TLCD has recently been used in several real-world buildings, including multiple high steel towers as well as the main towers of a cable-stayed bridge. The use of a TLD and TLCD (water tank) as a passive TMD is still being researched, and several studies have been published with data that demonstrate a decrease in seismic response of the structure.

Reiterer et al., (2007) [12] Suggested a TLCD for bridge vertical vibration suppression. The study's goal was to create active control systems. According to the TLCD design, the damping coefficient is automatically adjusted to its ideal value. They came to the conclusion that active control methods may be used to optimize the TLCD eigen frequency and damping coefficient.

A.Di Matteo1, (2014) [14] Main objective was to developed a mathematical model for TLCD by combining fractional derivatives and prior ideas to derive an equation of motion for the fluid inside the TLCD. In contrast to the conventional mathematical model, they concluded that the formulation of the updated linear fractional for frequency domain findings can properly antcipate the TLCD response.

Soliman I.M, (2016) [15] Controlling the damping screen(s) angle of inclination and the related loss coefficient was investigated as a control method for a semi-active TLD (SA-TLD). A gain scheduling strategy is used in this method. The study evaluated the responses of an SA-TLD control system with a typical passive TLD control system, as well as the fluid amplitude response for both systems.

David Saigea, (2017) [16] The objective of study was to reduce the human-induced vibrations of footbridges, a TMD with an eddy current damper was proposed. When a non-magnetic conductive plate is subjected to a time-varying magnetic field, eddy currents are produced. The conclusion reached was that eddy current dampers are a good TMD component because they allow for more precise tuning and the frequency adjusted remains constant over time.

Vahini. M, Akshatha N.S, (2018) [18] They study that the structures of G+10, G+20, and G+30 story height of structural models are investigated, both with and without adjusted liquid dampers. The vulnerability of buildings with and without tuned liquid dampers under various load circumstances is investigated, and seismic region 3 with varied water depths is used for the study. Building analysis is carried out at various heights to analyze the seismic behaviors of structures without and with adjusted liquid dampers. The conclusion of current research gives useful data on the parameters like lateral displacement, story drift, and base shear. E-Tabs software is used to do the analysis.

2.2 Aim and Objective:

The main aim of this study is to investigate about the results of regular building under seismic loading condition using ETABS. Time history analysis was used to examine the response of a building with and without Tuned Liquid Column Damper.

1. Create of plan, elevation and 3D view of G+12, G+17, G+20, G+24 floor regular building using ETABS 2019.

2. Apply boundary and loading conditions using Indian standards for Seismic, live and dead load. Codes used for the load IS 1893, IS 875.

3. Analysis results like story displacement, story drift, story shears etc. with all types cases that software ETABS created.

CHAPTER 3

METHODOLOGY

This chapter starts with a TMD design example and a brief explanation of some of the tuned mass damper methods used in constructing structures.

3.1 SDOF—TMD system (Single degree of freedom system)

Figure 3.1 shows one TMD system with a single degree of freedom (SDOF). Because TMDs are most efficient for periodic loading rather than random excitations from earthquakes, vortex shedding is represented by a dynamic wind loading, p. The mass, stiffness, and damping of the structure are represented by m, k, and c, respectively, while the damper characteristics are represented by m_d, k_d, *and* c_d **[9].**

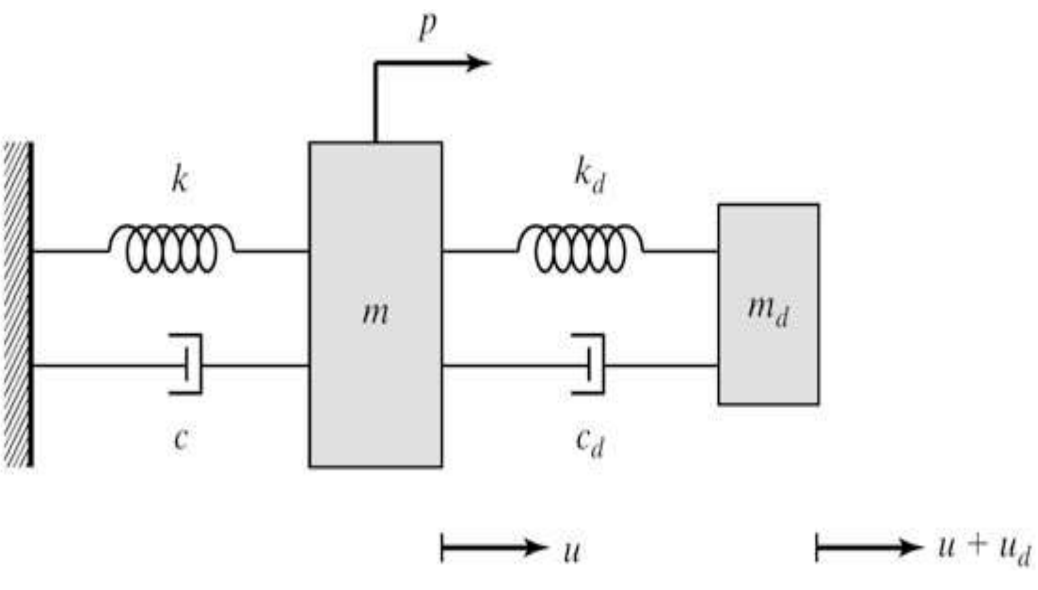


Figure 3. 1 SDOF—TMD system

The governing equations for this system are as follows:

Primary mass:

$$(m + m_d)\ddot{u} + c\dot{u} + ku = p - m_d\ddot{u}_d \qquad \textbf{(Eqn. 3.1)}$$

Damper:

$$m_d\ddot{u}_d + c_d\dot{u}_d + k_d u_d = -\, m_d\ddot{u} \qquad \textbf{(Eqn. 3.2)}$$

Selecting a mass ratio (m) that gives the necessary equivalent structural damping is the first step in TMD design. The ideal damping ratio ($\xi_{d|opt}$) and frequency ratio (f_{opt}) are then calculated using charts and equations published previously by Den Hartog and Tsai & Lin, or by numerical optimization. The TMD properties may be estimated using the formulae below with these values [9] 2014 (Connor & Laflamme) .

$$m_d = \overline{m}.\, m \qquad \textbf{(Eqn. 3.3)}$$

$$k_d = \overline{m}\, f^2_{opt}\, .k \qquad \textbf{(Eqn. 3.4)}$$

$$\omega_d^2 = k_d \,/\, m_d \qquad \textbf{(Eqn. 3.5)}$$

$$c_d = 2\, \xi_{d|opt}\omega_d m_d \qquad \textbf{(Eqn. 3.6)}$$

The above equations may be utilised for multi degree of freedom (MDOF) systems, with the mass and stiffness of the structure substituted by the modal mass ($\overline{m}$) and modal stiffness (k). Except from that, the design method remains the same.

3.2 Tuned Liquid Column Dampers

The governing equations for the TLCD are derived from the liquid's drag force (F_d) and the friction force (F) acting at the TLCD's contact with the main mass, as illustrated in Figure. Connor & Laflamme (2014) as shown above in fig. 1.3, used conservation of energy principles to compute these forces **[9].**

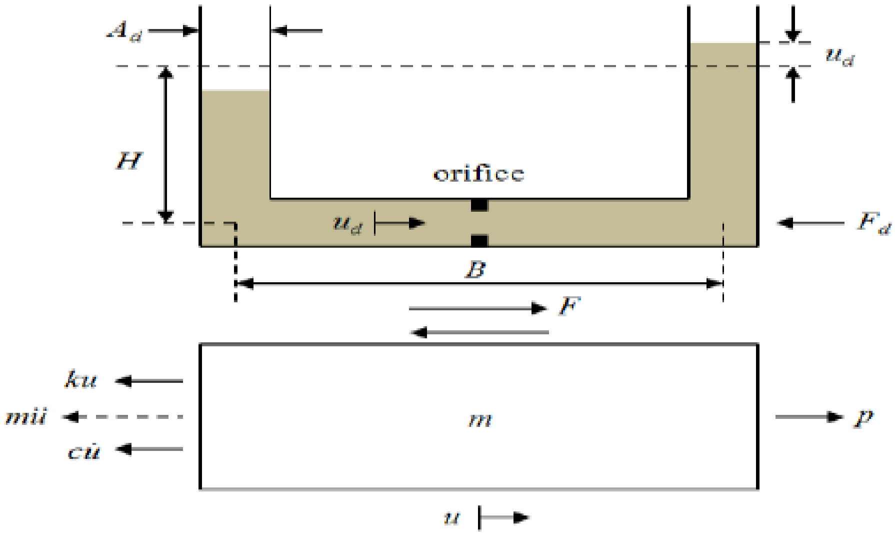


Figure 3. 2 TLCD Model (Adapted from Connor & Laflamme, 2014)

The following governing equations are obtained by substituting F and F_d into the equations of motion for this system:

Primary mass:

$$m\ddot{u} + c\dot{u} + ku + \rho A_d(B+2H)\,\ddot{u} + \rho' A_d B\ddot{u} = p \qquad \textbf{(Eqn. 3.7)}$$

Damper:

$$F_d = -\,[\rho' A_d B\ddot{u} + \rho' A_d\,(B+2H)\,\ddot{u} + \alpha\,\rho' g A_d\, u_d\,] \qquad \textbf{(Eqn. 3.8)}$$

Where ρ' represents the fluid density, B represents the damper width, H represents the stem height, A_d represents the damper cross-sectional area, and is a geometric constant.

Using L_d as the total damper length (B + 2H) and B/L_d as the width-to-total-length ratio, the following damping characteristics may be calculated:

$$m_d = \rho' A_d\, L_d \qquad \textbf{(Eqn. 3.9)}$$

$$k_d = \alpha\, \rho' g A_d \qquad \textbf{(Eqn. 3.10)}$$

Where, $\alpha = 1$, if $\beta = 1$ and $\alpha = 2$, if $\beta < 1$

$$F_d = c_{eq}\dot{u}_d \qquad \textbf{(Eqn. 3.11)}$$

Now, Eq. 3.7 and Eq. 3.8 can be written as:

Primary mass:

$$(m + m_d)\ddot{u} + c\dot{u} + ku = p - \beta m_d \ddot{u}_d \qquad \textbf{(Eqn. 3.12)}$$

Damper:

$$m_d \ddot{u}_d + c_d \dot{u}_d + k_d u_d = -\beta m_d \ddot{u} \qquad \textbf{(Eqn. 3.13)}$$

Because the TLCD's fluid damping is nonlinear, this formulation uses an equivalent viscous damping constant (ceq), which is determined by equating the TLCD's energy dissipation (through hysteretic loops) to a viscous damper. Except for the β term, the governing equations of the TMD (Eqn. 3.1 and 3.2) and the TLCD (Eqn. 3.12 and 3.13) are identical following these changes. Furthermore, Connor & Laflamme (2014) calculated that the TLCD is most effective when β = 1, indicating that the fluid only rests in the horizontal section of the TLCD in the steady state. The TMD governing equations and design procedure will be employed for both mass damping systems in this work since TLCDs will be built under this condition.

3.3 Modelling using a finite element package ETABS

In present project work, model G+12, G+17, G+20, and G+24 with and without TLCD construction are taken into account. The performance with and without Tuned Liquid Column Damper is analysed by time history analysis.

3.3.1 ETABS (Extended Three-dimensional Analysis of Building System)

ETABS software is used to model and analyze the data. ETABS is a powerful software and structure system developed by Inc. in Berkeley, California, that verifies a structural engineer's study and design skills. ETABS is a modern software that is convenient to use and is built particularly for the design and analysis of building systems. It comes with an inbuilt graphical interface that allows for advanced modelling and design methods, and it uses a common database. The software on the gadget is really simple to use. The gridlines, content property, and object position on the grid will all be defined by the user.

ETABS has the following features and benefits:

a) ETABS numerical input produces layout technique was intended to overcome one form of physical and numerical users can benefit with type structure. As a result, this data analysis and design process improves data planning and interpretation.

b) As simple specialists put nonlinear dynamic analysis procedures, the necessity for particular purpose software was never slowly apparent.

c) ETABS software is the most practical and well organized tool for static and dynamic analysis of multi-story buildings and shear wall.

d) ETABS recently obtain a variety of users behaviours and established the standard programming plan for organizations.

Before running the simulation, all required inputs, material properties, design parameters, analysis parameters, and boundary conditions were applied in accordance with Indian Civil Engineering standards. The stages of solving simulation are as follows:

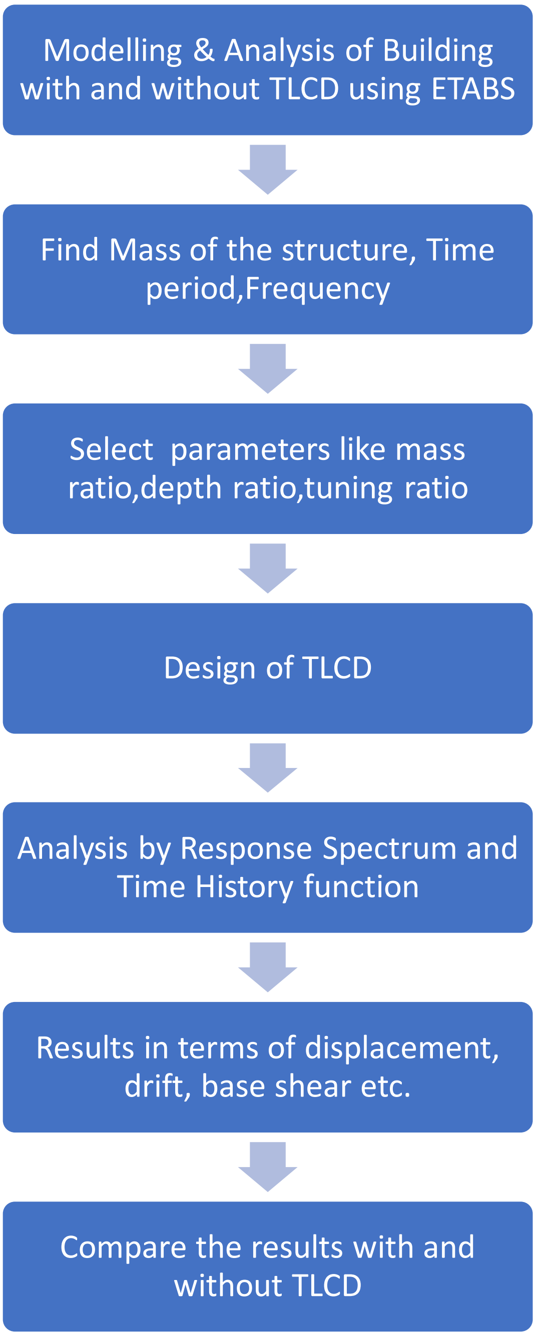


Figure 3. 3 Flow chart

3.3.2 Analytical model overview

In ETABS, the G+12, G+17, G+20 and G+24 building is analysed. These are the regular building that is taken into consideration in the same plan.

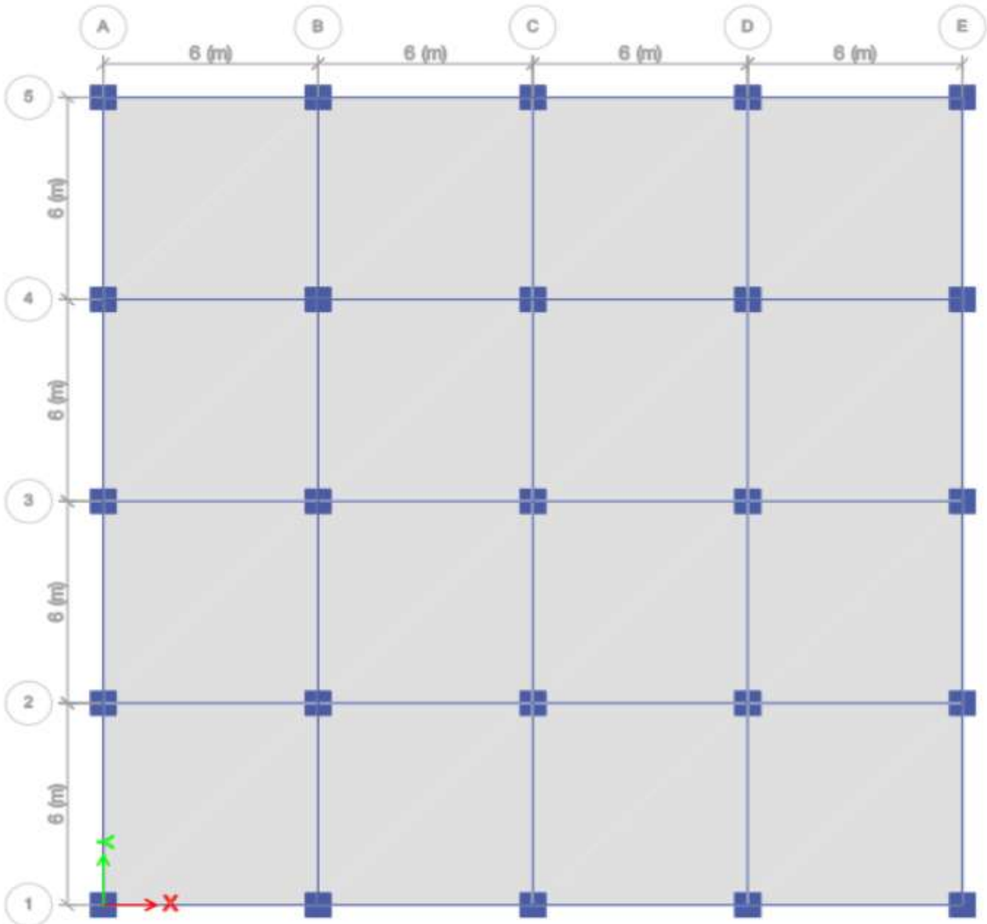


Figure 3. 4 Plan view

3.3.3 3D view of building as shown below as:

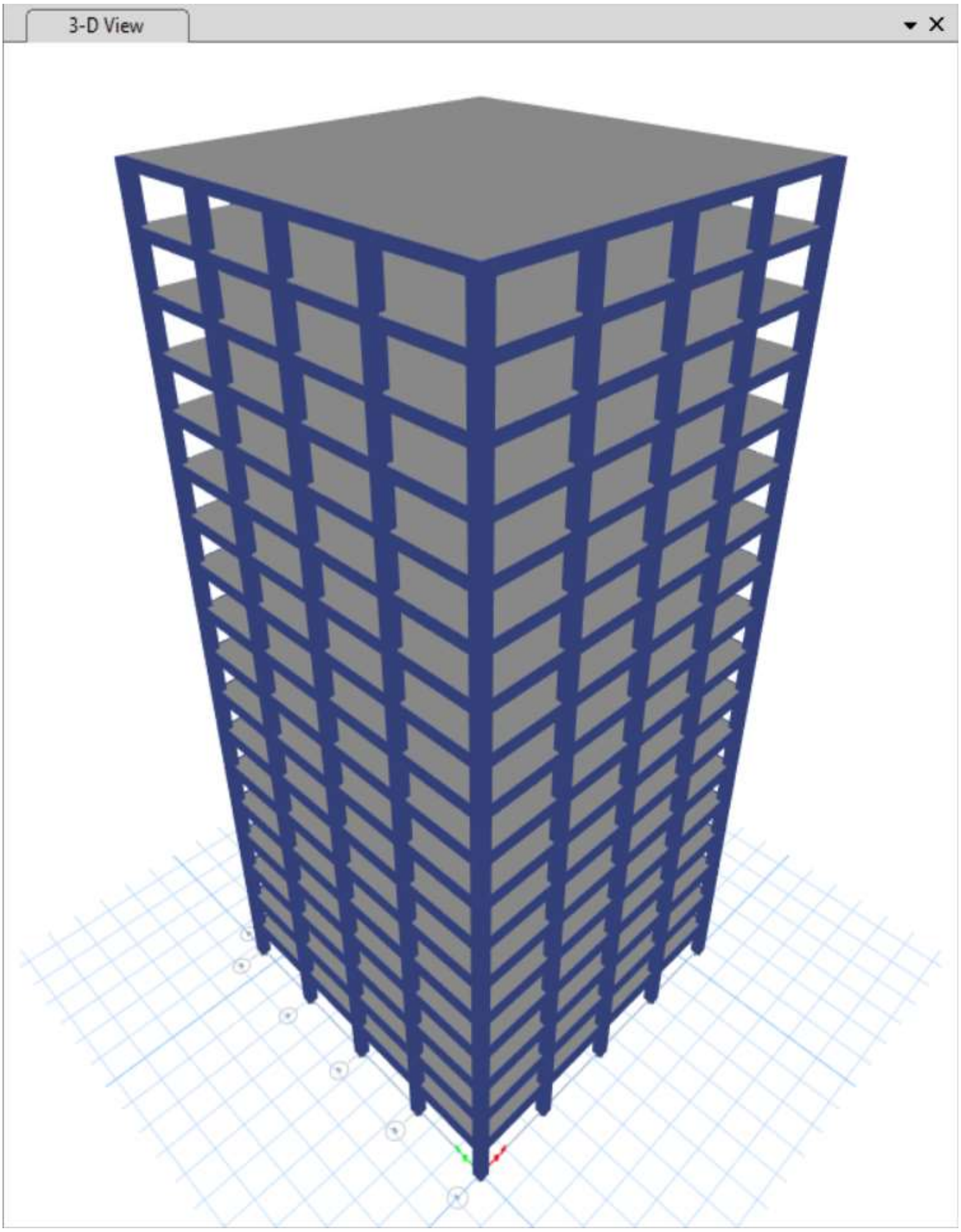


Figure 3. 5 3D view

3.3.4 Assigning the support conditions and properties of building

The XY plane view is chosen as the structure's base in the arrangement, and a fixed condition was assigned.

Figure 3. 6 Joint Restraints at base

3.3.5 Defining structural element and material properties

The geometric properties used for the model are as follows:

Dimension of Structure: 24m X 24m

Storey Height: 3 m

Structural Element	**Size of Element**
Column size:	750mm X 750 mm
Beam size:	500mm X 500 mm
Slab thickness:	200 mm
Wall thickness	230 mm

Table 3. 1 Dimensions of structural element

The Indian standard M30 cement concrete design is taken into account.

HYSD rebar of **Fe500** as per Indian standard is considered.

1. Code used: IS 1893:2016, IS 456:2000 & IS 875:1987
2. Earthquake force range: Base to Top story
3. Support condition: Fixed support

S.no	Particulars	Zone no. (IV)
1.	Earthquake Zone	0.24
2.	Importance Factor	1.2
3.	Type Of Soil	Type II (Medium Soil)
4.	Reduction factor	5

Table 3. 2 Particulars according to IS 1893:2016

3.4 Applying loads according Indian Codes

3.4.1 Dead Load

The unnecessary loads are produced by all permanent structures of the building. The dead load will be the weights of walls, partitions, floor finishes, false ceilings, false floors, and any additional permanent structures in the buildings.

3.4.2 Imposed Load

The weight of moveable partitions, dispersed and concentrated loads, load due to have an influence on and vibration, and dust loads are all examples of imposed loads created by the apparent use or occupancy of a structure. Live loads, also known as imposed loads. Wind, seismic activity, snow, and temperature changes, structural creep and shrinkage, and uneven settlements to which the structure may be exposed are not considered applied loads.

Loads on building assigned

Dead load	1.5 Kn/m^2
Live load	3 Kn/m^2
Wall load	11.5Kn/m^2

Table 3. 3 Load assigned

3.4.3 Seismic Load

Seismic analysis is a critical tool in earthquake engineering because it makes it easier for engineers to determine the structural response to a variety of seismic excitations. Previously, structures were primarily designed to resist gravitational loads.; however, seismic analysis is the most recent invention. It's a structural graph and structural evaluation sector with a frequent earthquakes.

There are a few unique earthquake analysis methods. The following are some of the types that were used in the task:

I. Equivalent Static Method
II. Response Spectrum Analysis
III. Time History Analysis

3.5 Analysis

To better understand TLCD's behaviour, the study took into account a variety of scenarios. Different parameters and elements of the structure were maintained constant while investigating a single parameter. The impact of TLCD is investigated.

a) The mass ratio is the mass of the TLCD in relation to the structure's mass. The mass ratio is taken into consideration to the tune of 2%.
b) The depth proportion refers to the distance between the fluid length in the sloshing course and the depth of water in TLD. The depth percentage is calculated to be 0.15, and the examination has been completed. Therefore, considered 0.15 in TLCD also as in TLD.
c) After TLD, the rate of decrease in displacement, drop in drift, and decrease in base shear rate are used to assess the outcomes.
d) The investigation was carried out using the dynamic analysis technique using IS codes.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Analysis of G+12 with and without Tuned Liquid Column Damper (TLCD)

First, analysis is carried out without Tuned Liquid Column Damper (TLCD) considering a regular building as shown below:

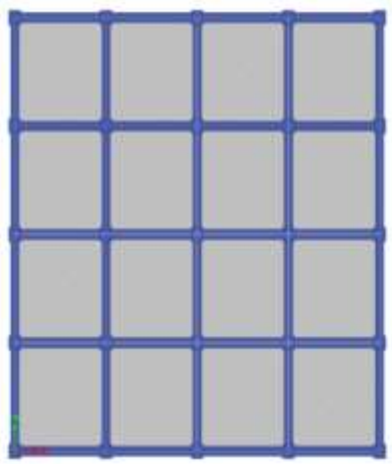


Figure 4. 1 Plan View

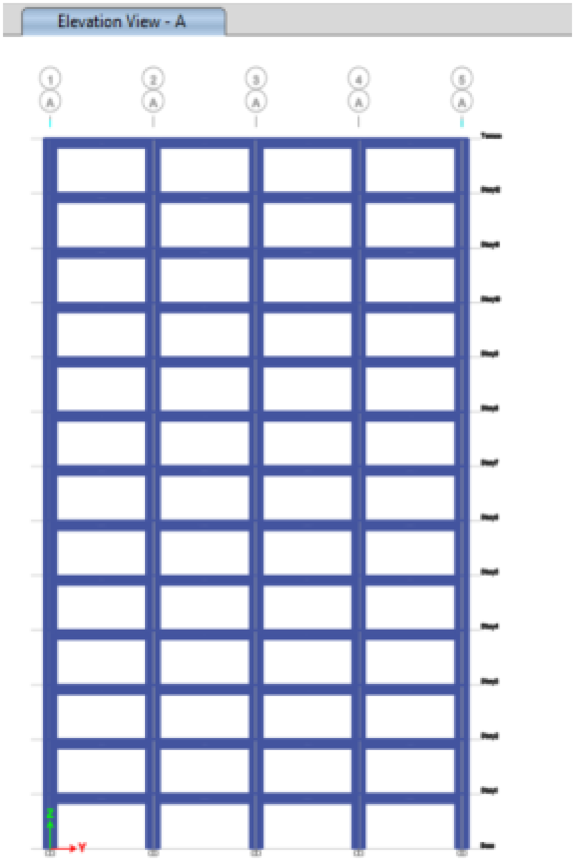


Figure 4. 2 Elevation view

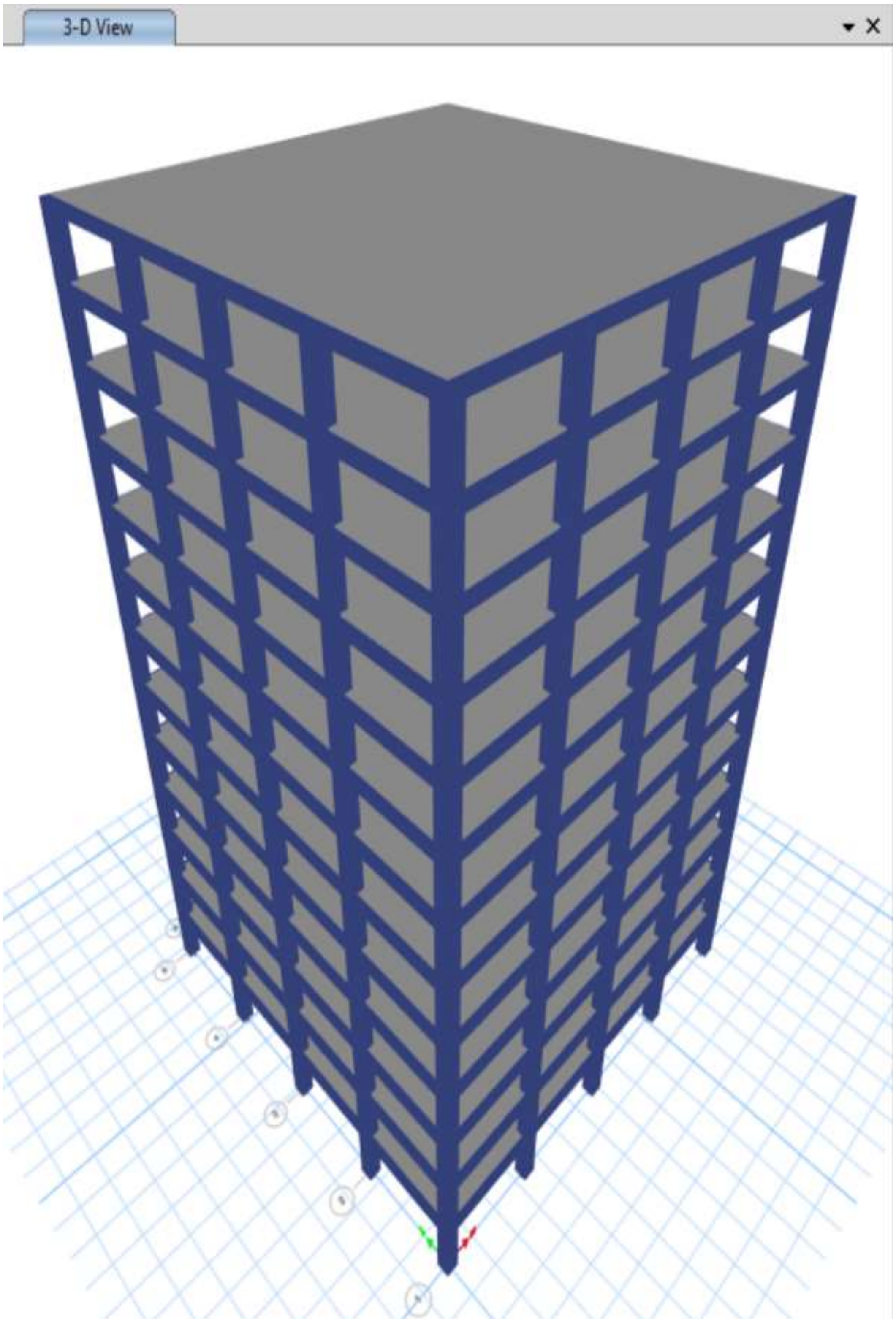


Figure 4. 3 3D View

4.1.1 Maximum Story Displacement

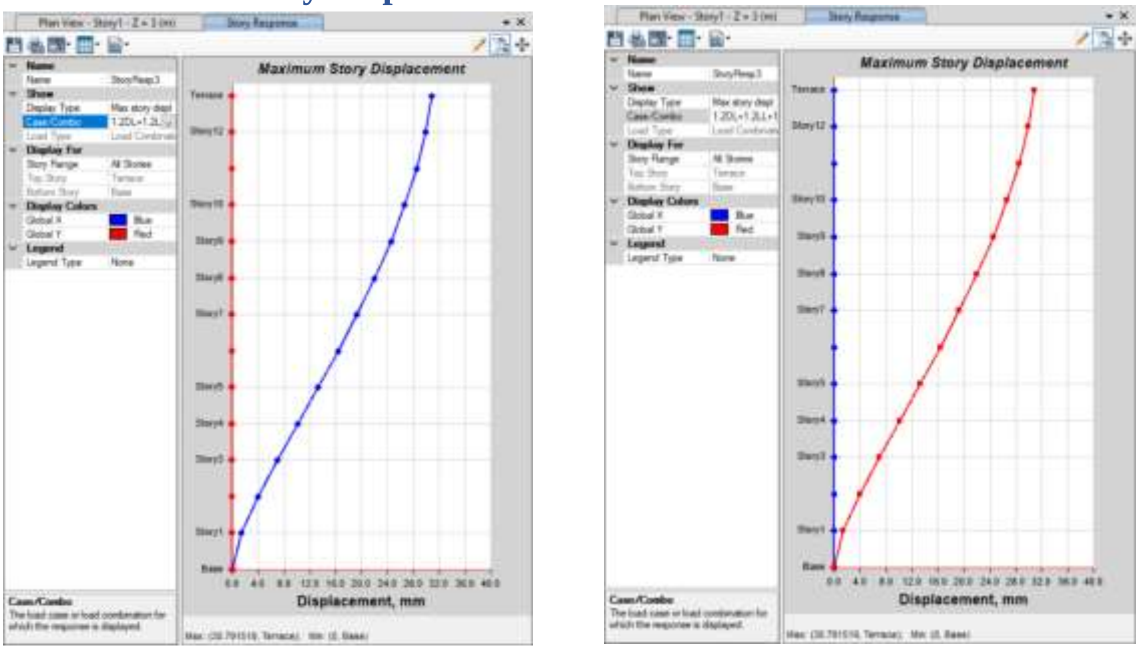


Figure 4. 4 Maximum Story Displacement

TABLE: Story Response				
Story	Elevation	Location	X-Dir	Y-Dir
	m		mm	mm
Terrace	39	Top	25.62	25.62
Story12	36	Top	24.85	24.85
Story11	33	Top	23.724	23.724
Story10	30	Top	22.235	22.235
Story9	27	Top	20.424	20.424
Story8	24	Top	18.345	18.345
Story7	21	Top	16.055	16.055
Story6	18	Top	13.605	13.605
Story5	15	Top	11.045	11.045
Story4	12	Top	8.421	8.421
Story3	9	Top	5.794	5.794
Story2	6	Top	3.27	3.27
Story1	3	Top	1.104	1.104
Base	0	Top	0	0

s

Table 4. 1 Maximum Story Displacement

4.1.2 Analysis of G+12 building with TLCD

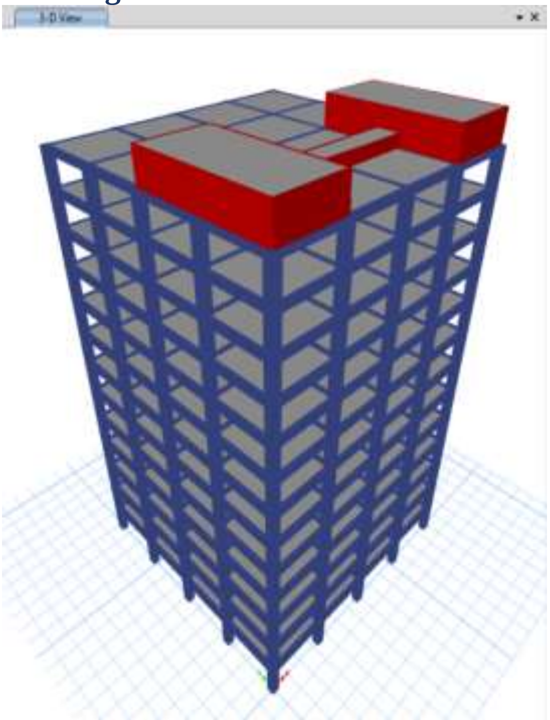
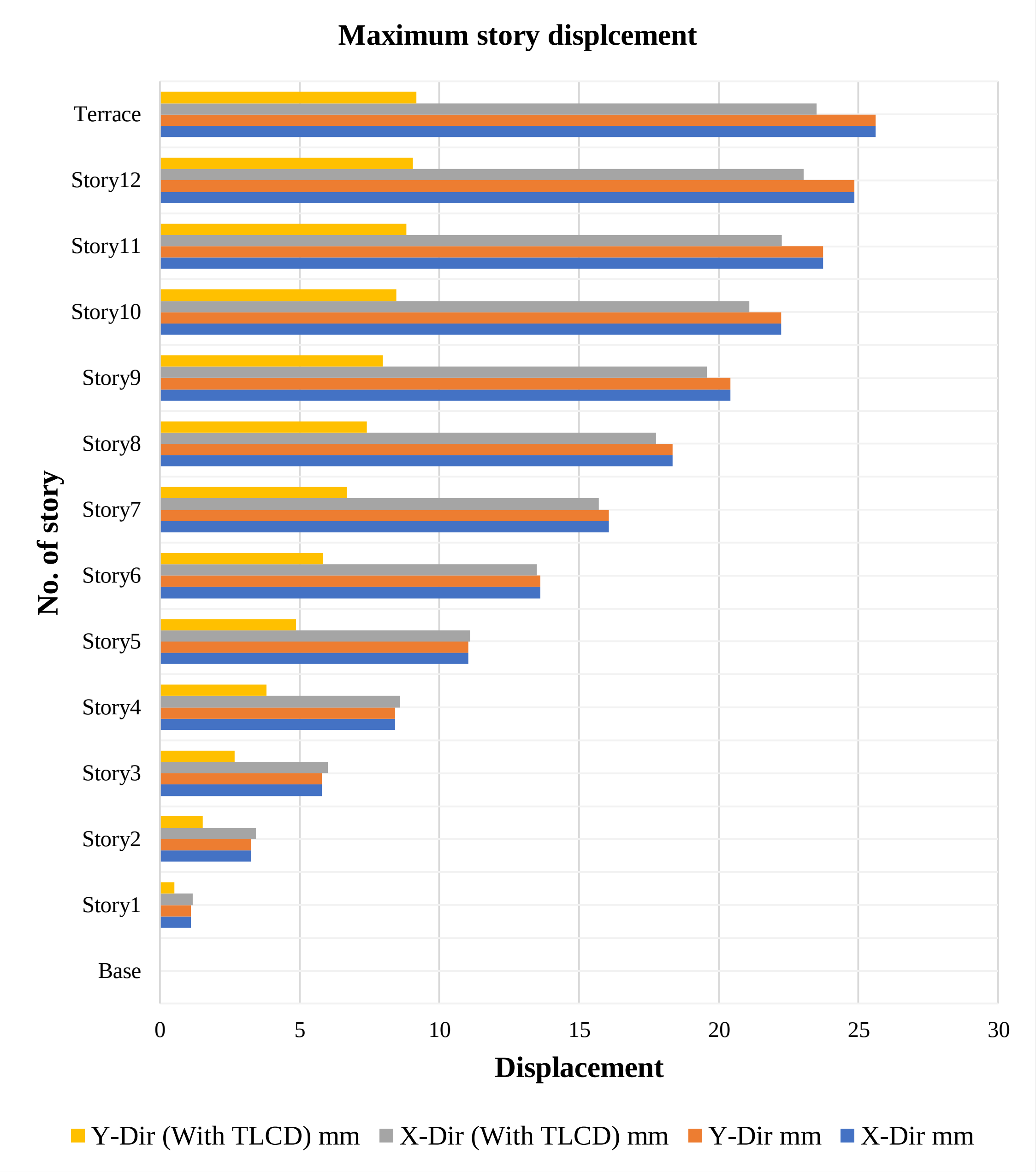


Figure 4. 5 G+12 building with TLCD (3D View)

TABLE: Story Response				
Story	Elevation	Location	X-Dir	Y-Dir
	m		mm	mm
Terrace	39	Top	23.506	9.188
Story12	36	Top	23.045	9.047
Story11	33	Top	22.264	8.818
Story10	30	Top	21.101	8.464
Story9	27	Top	19.578	7.977
Story8	24	Top	17.761	7.4
Story7	21	Top	15.713	6.69
Story6	18	Top	13.486	5.846
Story5	15	Top	11.105	4.88
Story4	12	Top	8.594	3.813
Story3	9	Top	6	2.676
Story2	6	Top	3.428	1.531
Story1	3	Top	1.165	0.521
Base	0	Top	0	0

Table 4. 2 Maximum Story Displacement

Maximum story displacement for G+12 building



Graph 4. 1 Maximum story displacement for G+12 building

Base reaction and Modal participating mass ratios for G+12 building (With TLCD)

TABLE: Base Reactions												
Output Case	Case Type	Step Type	Step Number	FX	FY	FZ	MX	MY	MZ	X	Y	Z
				kN	kN	kN	kN-m	kN-m	kN-m	m	m	m
Modal	LinModEigen	Mode	1	0	-1.3458	0	38.4222	0	-16.1493	0	0	0
Modal	LinModEigen	Mode	2	1.8523	0	0	0	50.7962	-31.0734	0	0	0
Modal	LinModEigen	Mode	3	1.3342	0	0	0	38.7318	9.8699	0	0	0
Modal	LinModEigen	Mode	4	0	-4.7576	0	-18.2135	0	-57.0915	0	0	0
Modal	LinModEigen	Mode	5	-3.9446	0	0	0	48.4924	41.8161	0	0	0
Modal	LinModEigen	Mode	6	-1.6892	0	0	0	-5.5006	85.4249	0	0	0
Modal	LinModEigen	Mode	7	0	-9.7757	0	53.5234	0	-117.3082	0	0	0
Modal	LinModEigen	Mode	8	-10.1639	0	0	5.325E-07	-77.5815	90.6667	0	0	0
Modal	LinModEigen	Mode	9	3.0559	-0.00000214	0	0.000003472	10.113	-178.9623	0	0	0
Modal	LinModEigen	Mode	10	0.000000889	17.4891	0	-10.9925	0.000002716	209.8696	0	0	0
Modal	LinModEigen	Mode	11	16.668	0.00001726	0	-0.00002071	-11.4241	-154.1404	0	0	0
Modal	LinModEigen	Mode	12	-5.6424	-0.00002296	0	0.00002051	-7.5494	307.0167	0	0	0
Dead	LinStatic			0	0	97358.4605	1146814.53	-1168302	0	0	0	0
Live	LinStatic			0	0	22464	269568	-269568	0	0	0	0
EQ-X	LinStatic			-2699.0523	0	0	0	-86547.5679	28918.7533	0	0	0
EQ-Y	LinStatic			0	-2699.0523	0	86547.5679	0	-32388.6277	0	0	0
TIME HISTORY FUNCTION	LinModHist	Max		1841.3606	0.0002	0	0.0001	53723.573	30918.9902	0	0	0
TIME HISTORY FUNCTION	LinModHist	Min		-2064.2669	-0.0001	0	-0.0002	-58712.1458	-29705.9997	0	0	0
1.2DEAD+1.2LIVE+1.2EQ-X	Combination			-3238.8628	0	143786.9526	1699659.036	-1829301	34702.5039	0	0	0
1.2DEAD+1.2LIVE -1.2EQ-X	Combination			3238.8628	0	143786.9526	1699659.036	-1621586	-34702.5039	0	0	0
1.2DEAD+1.2LIVE+1.2EQ-Y	Combination			0	0	143786.9526	1699659.036	-1725443	0	0	0	0
1.2DEAD+1.2LIVE -1.2EQ-Y	Combination			0	0	143786.9526	1699659.036	-1725443	0	0	0	0

Table 4. 3 Base reaction

TABLE: Modal Participating Mass Ratios													
Case	Mode	Period	UX	UY	UZ	SumUX	SumUY	SumUZ	RX	RY	RZ	SumRX	SumRY	SumRZ
		sec												
Modal	1	1.538	0	0.7915	0	0	0.7915	0	0.2144	0	0	0.2144	0	0
Modal	2	1.241	0.6353	0	0	0.6353	0.7915	0	0	0.115	0.1717	0.2144	0.115	0.1717
Modal	3	1.078	0.1876	0	0	0.823	0.7915	0	0	0.059	0.6371	0.2144	0.174	0.8088
Modal	4	0.488	0	0.1004	0	0.823	0.8919	0	0.4906	0	0	0.705	0.174	0.8088
Modal	5	0.475	0.0618	0	0	0.8848	0.8919	0	0	0.5284	0.0004	0.705	0.7025	0.8092
Modal	6	0.395	0.0054	0	0	0.8902	0.8919	0	0	0.0141	0.0793	0.705	0.7166	0.8885
Modal	7	0.269	0	0.0388	0	0.8902	0.9306	0	0.0788	0	0	0.7838	0.7166	0.8885
Modal	8	0.266	0.0406	0	0	0.9308	0.9306	0	0	0.0628	0.0025	0.7838	0.7794	0.891
Modal	9	0.223	0.0018	0	0	0.9326	0.9306	0	0	0.0047	0.0383	0.7838	0.7841	0.9294
Modal	10	0.174	0	0.0219	0	0.9326	0.9526	0	0.0737	0	0	0.8575	0.7841	0.9294
Modal	11	0.173	0.0193	0	0	0.9519	0.9526	0	0	0.073	0.0009	0.8575	0.8571	0.9303
Modal	12	0.147	0.0012	0	0	0.9531	0.9526	0	0	0.0036	0.0204	0.8575	0.8608	0.9507

Table 4. 4 Modal participating mass ratios

4.2 Analysis of G+17 with and without Tuned Liquid Column Damper (TLCD)

Now, analysis is carried out without considering the Tuned Liquid Column

Damper as shown below:

4.2.1 3D view of building

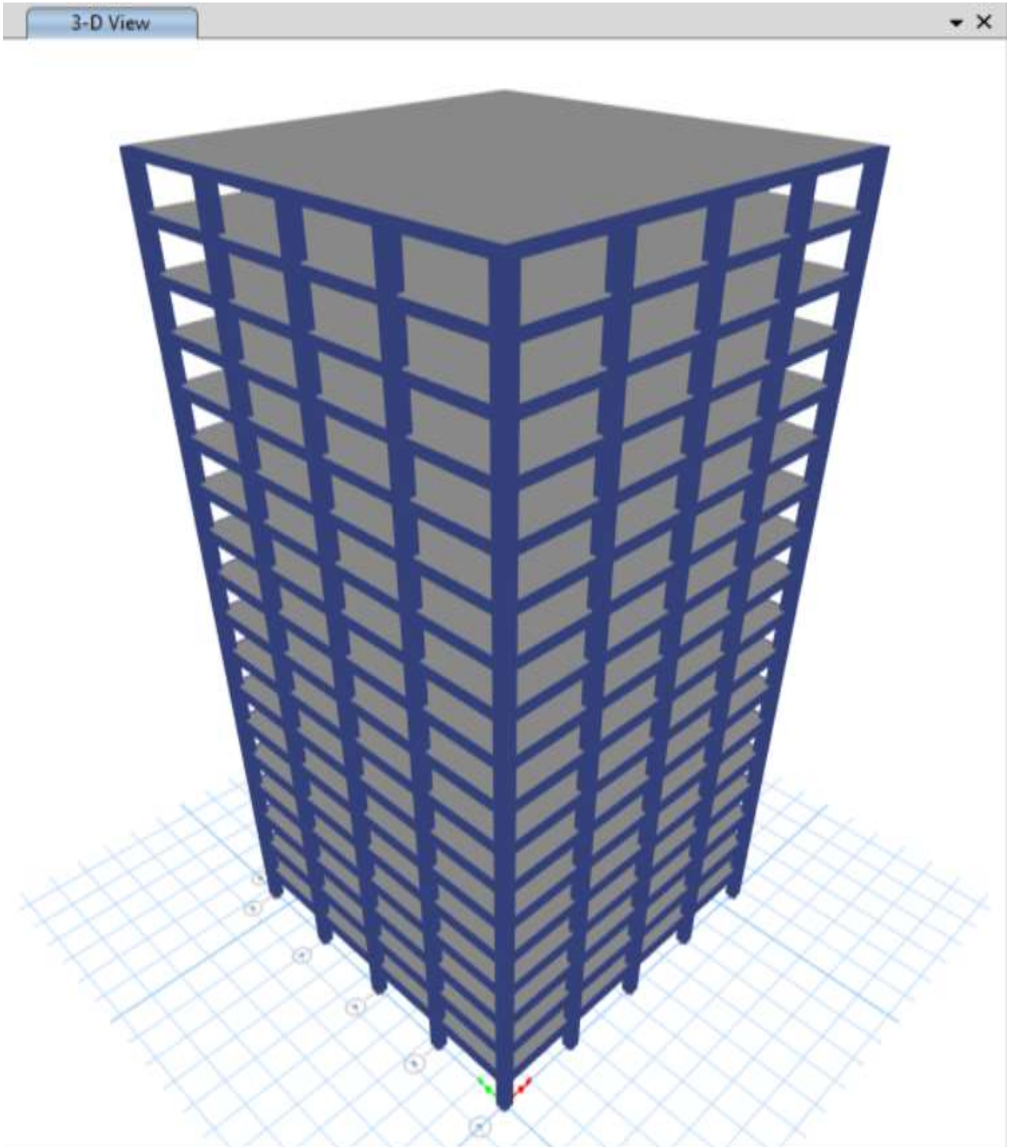


Figure 4. 6 3D view of building

4.2.2 Maximum Story Displacement

TABLE: Story Response				
Story	Elevation	Location	X-Dir	Y-Dir
	m		mm	mm
Terrace	54	Top	36.753	36.753
Story17	51	Top	36.044	36.044
Story16	48	Top	35.063	35.063
Story15	45	Top	33.789	33.789
Story14	42	Top	32.242	32.242
Story13	39	Top	30.451	30.451
Story12	36	Top	28.451	28.451
Story11	33	Top	26.274	26.274
Story10	30	Top	23.949	23.949
Story9	27	Top	21.505	21.505
Story8	24	Top	18.969	18.969
Story7	21	Top	16.363	16.363
Story6	18	Top	13.712	13.712
Story5	15	Top	11.035	11.035
Story4	12	Top	8.36	8.36
Story3	9	Top	5.724	5.724
Story2	6	Top	3.219	3.219
Story1	3	Top	1.084	1.084
Base	0	Top	0	0

Table 4. 5 Maximum Story Displacement

4.2.3 Analysis of G+17 building with TLCD

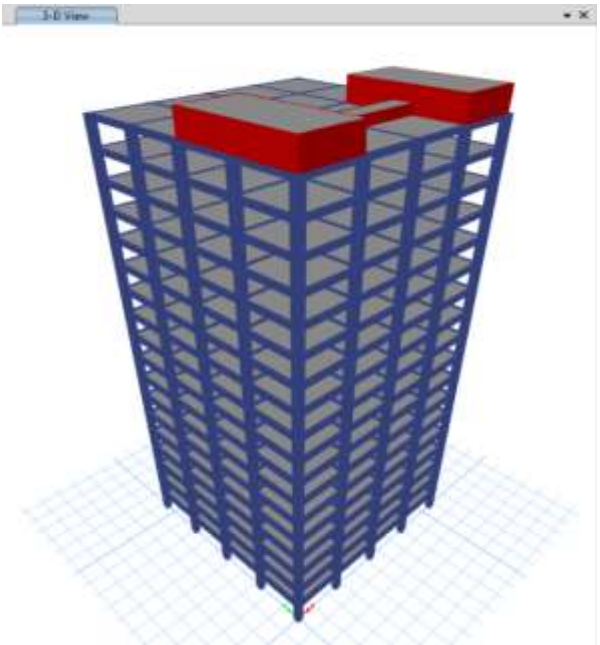


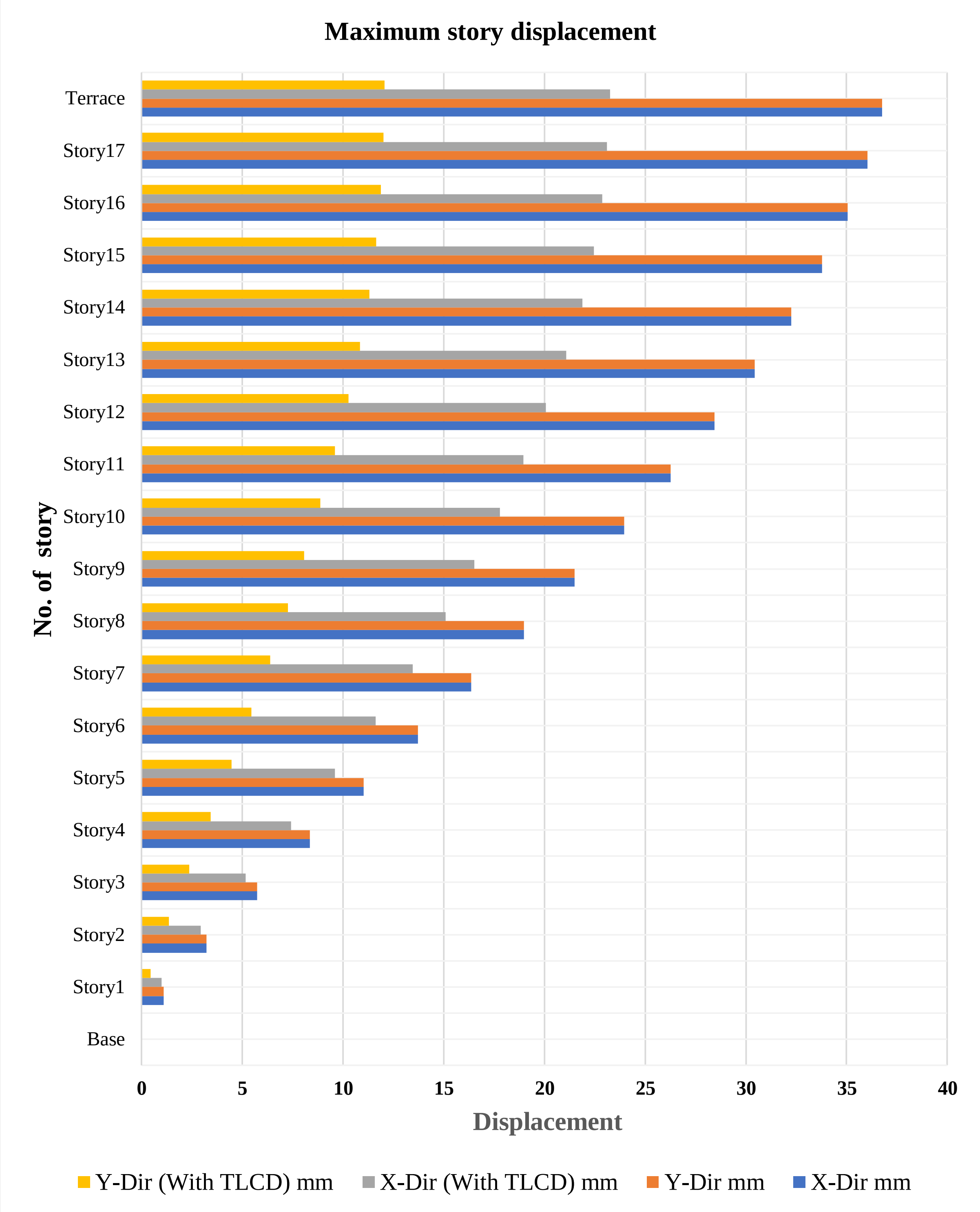
Figure 4. 7 G+17 building with TLCD (3D View)

4.2.4 Maximum Story Displacement

TABLE: Story Response				
Story	Elevation	Location	X-Dir	Y-Dir
	m		mm	mm
Terrace	54	Top	23.264	12.065
Story17	51	Top	23.114	12.006
Story16	48	Top	22.861	11.885
Story15	45	Top	22.463	11.656
Story14	42	Top	21.883	11.307
Story13	39	Top	21.082	10.838
Story12	36	Top	20.077	10.261
Story11	33	Top	18.945	9.594
Story10	30	Top	17.777	8.86
Story9	27	Top	16.522	8.077
Story8	24	Top	15.094	7.254
Story7	21	Top	13.466	6.378
Story6	18	Top	11.626	5.447
Story5	15	Top	9.598	4.461
Story4	12	Top	7.425	3.43
Story3	9	Top	5.166	2.378
Story2	6	Top	2.937	1.349
Story1	3	Top	0.995	0.456
Base	0	Top	0	0

Table 4. 6 Maximum Story Displacement

Maximum story displacement for G+17 building



Graph 4. 2 Maximum story displacement for G+17 building

Base reaction and Modal participating mass ratios for G+17 building (With TLCD)

TABLE: Base Reactions												
Output Case	Case Type	Step Type	Step Number	FX	FY	FZ	MX	MY	MZ	X	Y	Z
				kN	kN	kN	kN-m	kN-m	kN-m	m	m	m
Modal	LinModEigen	Mode	1	0	-0.7737	0	30.4474	0	-9.2849	0	0	0
Modal	LinModEigen	Mode	2	1.0955	0	0	0	40.7865	-20.0612	0	0	0
Modal	LinModEigen	Mode	3	-1.088	0	0	0	-42.3827	-3.3718	0	0	0
Modal	LinModEigen	Mode	4	0	-2.6979	0	-15.2424	0	-32.3747	0	0	0
Modal	LinModEigen	Mode	5	2.0493	0.000001591	0	-0.00000264	-50.762	-23.6133	0	0	0
Modal	LinModEigen	Mode	6	-1.0073	0	0	0	-9.0899	48.0996	0	0	0
Modal	LinModEigen	Mode	7	0.000002174	5.1609	0	-36.0474	-0.0000028	61.9309	0	0	0
Modal	LinModEigen	Mode	8	5.5387	-0.000002281	0	0.000004322	64.1606	-48.1294	0	0	0
Modal	LinModEigen	Mode	9	-1.6893	-5.476E-07	0	9.669E-07	-2.713	96.6465	0	0	0
Modal	LinModEigen	Mode	10	-0.000002616	-8.5637	0	1.2205	-0.000008222	-102.7641	0	0	0
Modal	LinModEigen	Mode	11	7.9195	-0.00001158	0	0.0000222	-23.1096	-69.8925	0	0	0
Modal	LinModEigen	Mode	12	-3.3639	-0.000005304	0	0.00001004	-8.4136	155.3773	0	0	0
Dead	LinStatic			0	0	135217.2847	1590376.616	-1622607	0	0	0	0
Live	LinStatic			0	0	31104	373248	-373248	0	0	0	0
EQ-X	LinStatic			-2602.0151	0	0	0	-115418.5258	27582.2664	0	0	0
EQ-Y	LinStatic			0	-2002.4341	0	88822.6947	0	-24029.2095	0	0	0
TIME HISTORY FUNCTION	LinModHist	Max		1938.5272	0.0003	0	0.0008	68870.7024	25606.5993	0	0	0
TIME HISTORY FUNCTION	LinModHist	Min		-1953.5338	-0.0004	0	-0.0006	-80330.1516	-28277.6848	0	0	0
1.2DEAD+1.2LIVE+1.2EQ-X	Combination			-3122.4181	0	199585.5416	2356349.54	-2533529	33098.7196	0	0	0
1.2DEAD+1.2LIVE -1.2EQ-X	Combination			3122.4181	0	199585.5416	2356349.54	-2256524	-33098.7196	0	0	0
1.2DEAD+1.2LIVE+1.2EQ-Y	Combination			0	0	199585.5416	2356349.54	-2395026	0	0	0	0
1.2DEAD+1.2LIVE -1.2EQ-Y	Combination			0	0	199585.5416	2356349.54	-2395026	0	0	0	0

Table 4. 7 Base reaction

TABLE: Modal Participating Mass Ratios													
Case	Mode	Period	UX	UY	UZ	SumUX	SumUY	SumUZ	RX	RY	RZ	SumRX	SumRY	SumRZ
		sec												
Modal	1	2.205	0	0.7902	0	0	0.7902	0	0.2129	0	0	0.2129	0	0
Modal	2	1.697	0.5556	0	0	0.5556	0.7902	0	0	0.0851	0.2539	0.2129	0.0851	0.2539
Modal	3	1.432	0.2781	0	0	0.8336	0.7902	0	0	0.0682	0.5623	0.2129	0.1533	0.8162
Modal	4	0.707	0	0.1015	0	0.8336	0.8917	0	0.4891	0	0	0.7021	0.1533	0.8162
Modal	5	0.678	0.0495	0	0	0.8831	0.8917	0	0	0.5546	5.64E-06	0.7021	0.7078	0.8162
Modal	6	0.562	0.0056	0	0	0.8887	0.8917	0	0	0.0097	0.0716	0.7021	0.7175	0.8878
Modal	7	0.396	0	0.0365	0	0.8887	0.9282	0	0.0749	0	0	0.777	0.7175	0.8878
Modal	8	0.391	0.0402	0	0	0.9289	0.9282	0	0	0.0537	0.0029	0.777	0.7712	0.8906
Modal	9	0.326	0.0018	0	0	0.9307	0.9282	0	0	0.0056	0.0364	0.777	0.7768	0.927
Modal	10	0.264	0	0.02	0	0.9307	0.9482	0	0.0681	0	0	0.845	0.7768	0.927
Modal	11	0.262	0.0165	0	0	0.9473	0.9482	0	0	0.068	0.0011	0.845	0.8448	0.9281
Modal	12	0.221	0.0015	0	0	0.9488	0.9482	0	0	0.0044	0.0176	0.845	0.8492	0.9457

Table 4. 8 Modal participating mass ratios

4.3 Analysis of G+20 with and without Tuned Liquid Column Damper (TLCD)

Now, analysis is carried out without considering the Tuned Liquid Column

Damper as shown below:

4.3.1 3D view of building

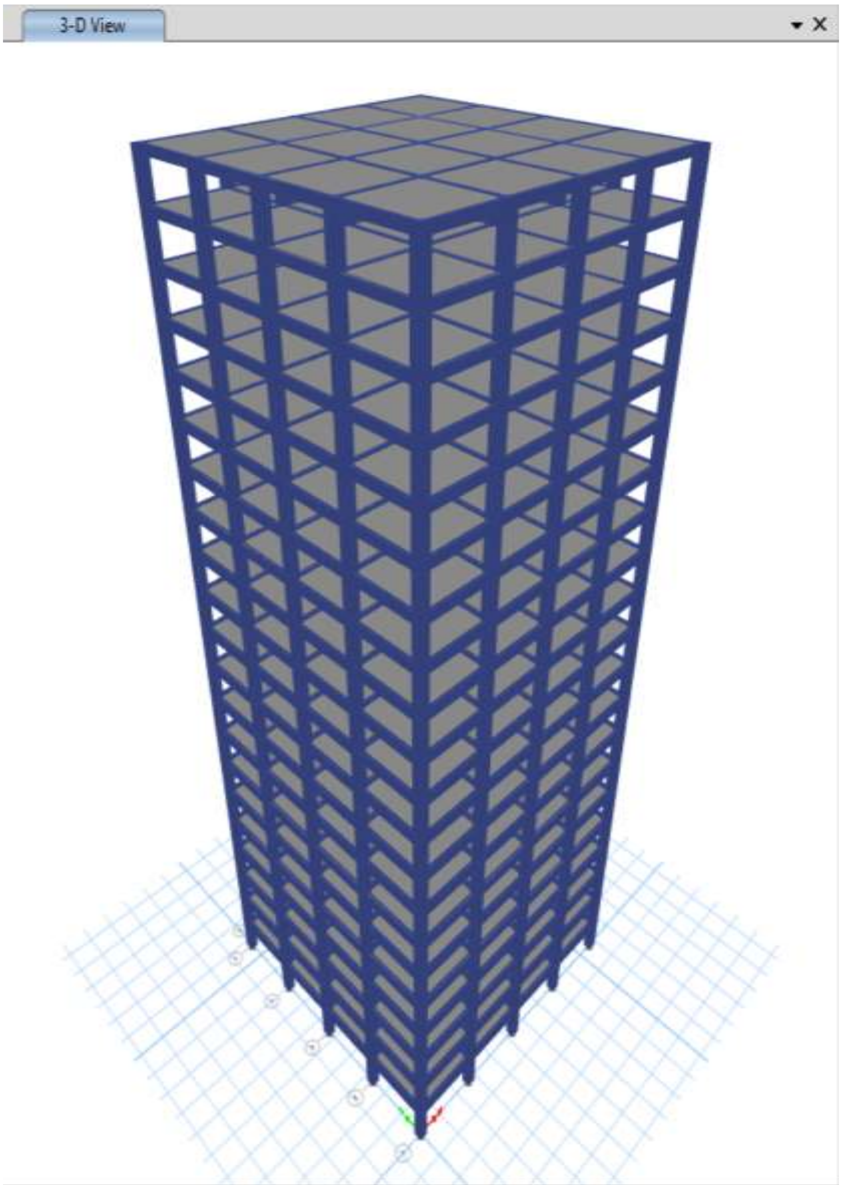


Figure 4. 8 3D view of building

4.3.2 Maximum Story Displacement

TABLE: Story Response				
Story	Elevation	Location	X-Dir	Y-Dir
	m		mm	mm
Terrace	63	Top	43.558	43.558
Story20	60	Top	42.845	42.845
Story19	57	Top	41.903	41.903
Story18	54	Top	40.712	40.712
Story17	51	Top	39.282	39.282
Story16	48	Top	37.627	37.627
Story15	45	Top	35.769	35.769
Story14	42	Top	33.732	33.732
Story13	39	Top	31.542	31.542
Story12	36	Top	29.22	29.22
Story11	33	Top	26.79	26.79
Story10	30	Top	24.272	24.272
Story9	27	Top	21.685	21.685
Story8	24	Top	19.047	19.047
Story7	21	Top	16.374	16.374
Story6	18	Top	13.681	13.681
Story5	15	Top	10.985	10.985
Story4	12	Top	8.306	8.306
Story3	9	Top	5.679	5.679
Story2	6	Top	3.19	3.19
Story1	3	Top	1.073	1.073
Base	0	Top	0	0

Table 4. 9 Maximum Story Displacement

4.3.3 Analysis of G+20 building with TLCD

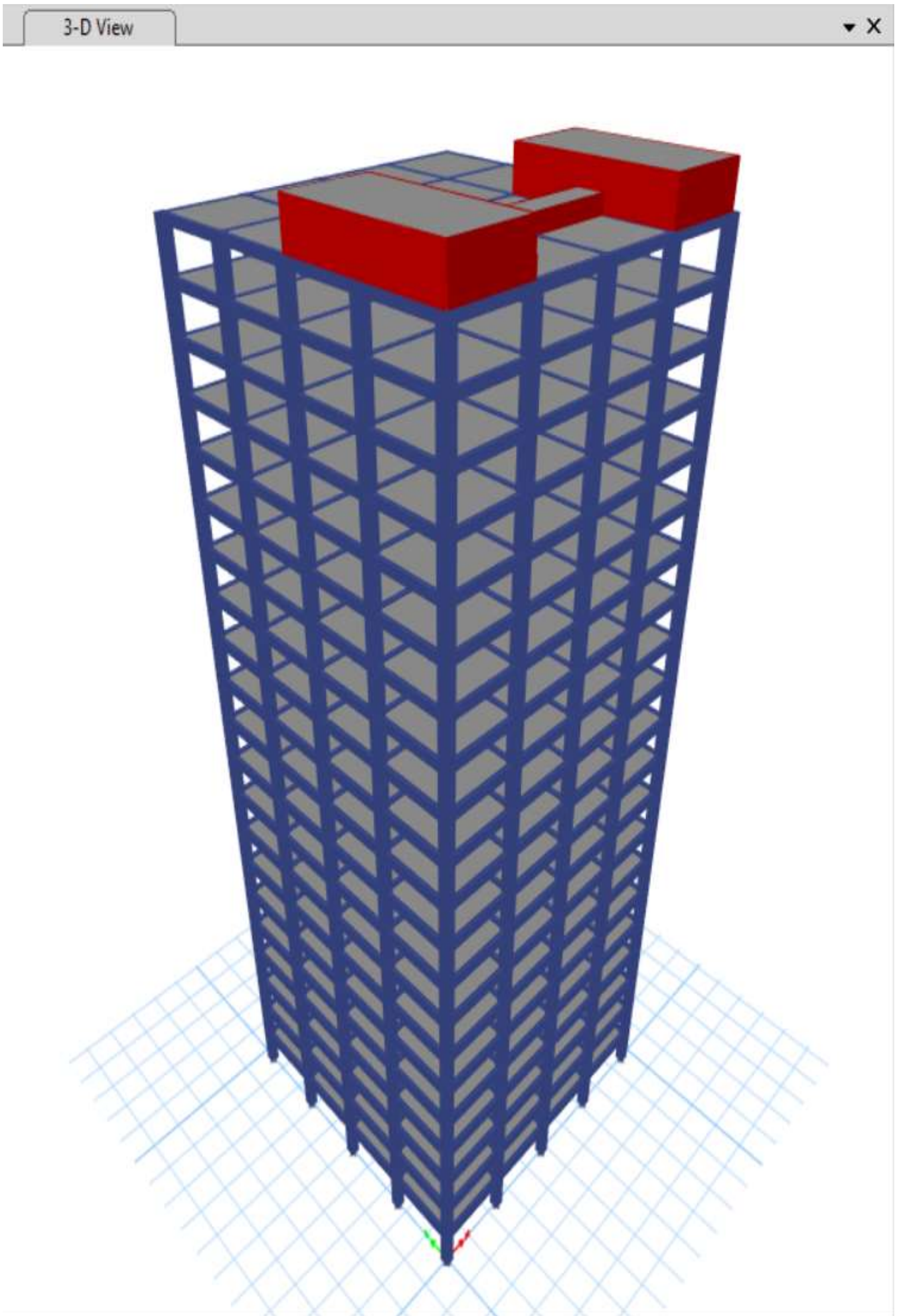


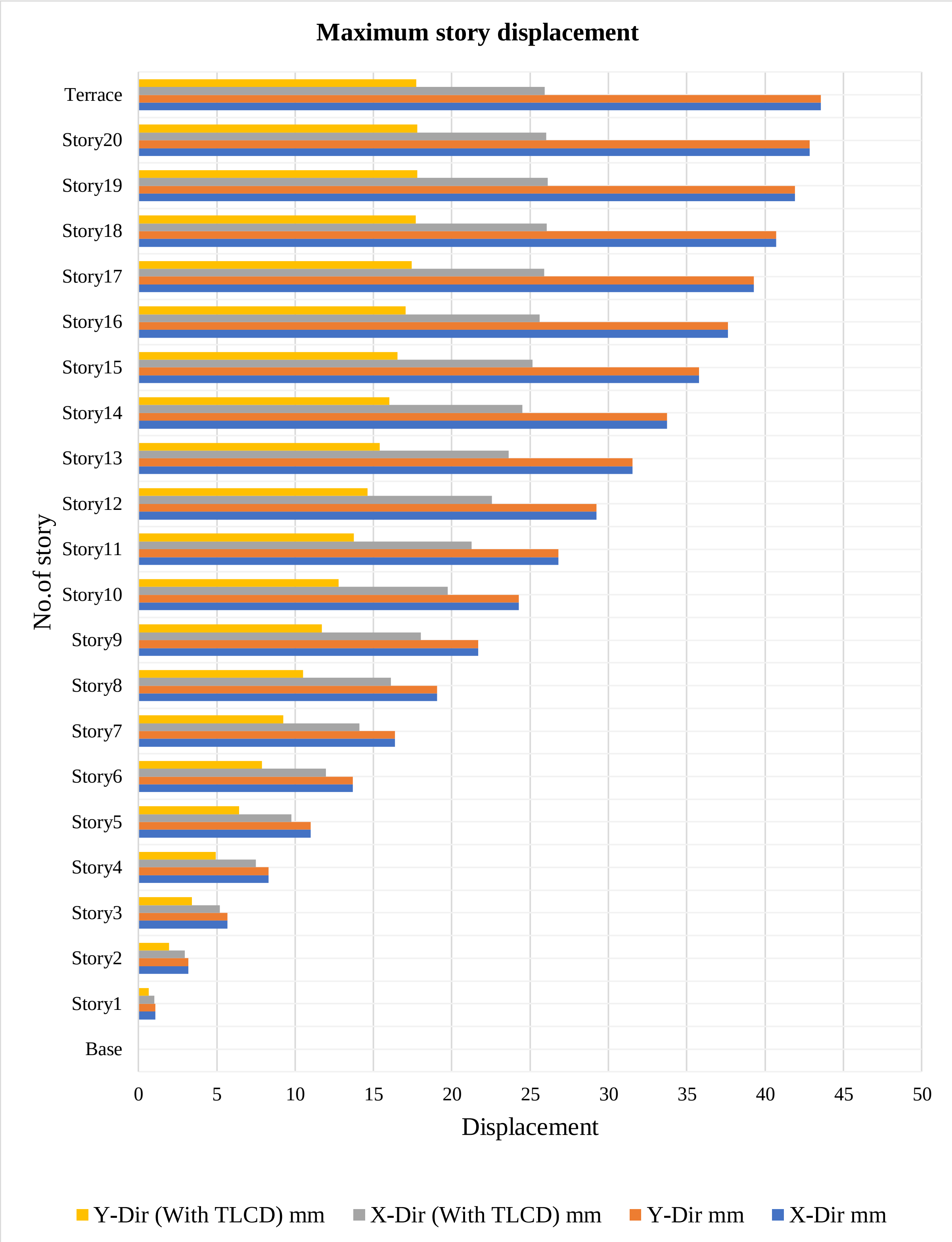
Figure 4. 9 G+20 building with TLCD (3D View)

4.3.4 Maximum Story Displacement

TABLE: Story Response				
Story	**Elevation**	**Location**	**X-Dir**	**Y-Dir**
	m		mm	mm
Terrace	63	Top	25.918	17.73
Story20	60	Top	26.04	17.801
Story19	57	Top	26.112	17.811
Story18	54	Top	26.074	17.695
Story17	51	Top	25.91	17.443
Story16	48	Top	25.606	17.046
Story15	45	Top	25.143	16.535
Story14	42	Top	24.493	16.022
Story13	39	Top	23.633	15.386
Story12	36	Top	22.552	14.631
Story11	33	Top	21.25	13.762
Story10	30	Top	19.731	12.784
Story9	27	Top	18.01	11.699
Story8	24	Top	16.12	10.513
Story7	21	Top	14.095	9.235
Story6	18	Top	11.969	7.872
Story5	15	Top	9.764	6.435
Story4	12	Top	7.497	4.942
Story3	9	Top	5.197	3.422
Story2	6	Top	2.95	1.94
Story1	3	Top	0.999	0.656
Base	0	Top	0	0

Table 4. 10 Maximum Story Displacement

Maximum story displacement for G+20 building



Graph 4. 3 Maximum story displacement for G+20 building

Base reaction and Modal participating mass ratios for G+20 building (With TLCD)

TABLE: Base Reactions												
Output Case	Case Type	Step Type	Step Number	FX	FY	FZ	MX	MY	MZ	X	Y	Z
				kN	kN	kN	kN-m	kN-m	kN-m	m	m	m
Modal	LinModEigen	Mode	1	0	-0.6083	0	27.7913	0	-7.299	0	0	0
Modal	LinModEigen	Mode	2	0.7425	0	0	0	31.2613	-17.2209	0	0	0
Modal	LinModEigen	Mode	3	-1.5406	0	0	0	-64.9566	4.3472	0	0	0
Modal	LinModEigen	Mode	4	0	-2.1312	0	-13.3349	-0.000001481	-25.5738	0	0	0
Modal	LinModEigen	Mode	5	1.1848	0	0	-6.114E-07	-78.7948	-19.9251	0	0	0
Modal	LinModEigen	Mode	6	0.7889	0	0	0	29.2749	-35.8312	0	0	0
Modal	LinModEigen	Mode	7	0.000004406	3.9975	0	-30.8329	0.000008681	47.9698	0	0	0
Modal	LinModEigen	Mode	8	-4.8023	5.982E-07	0	8.481E-07	-86.9688	42.3963	0	0	0
Modal	LinModEigen	Mode	9	-0.9906	-0.000001619	0	-0.000002382	11.7457	72.7482	0	0	0
Modal	LinModEigen	Mode	10	-5.794E-07	-6.3944	0	-1.1332	-0.000001187	-76.7333	0	0	0
Modal	LinModEigen	Mode	11	-5.5312	-0.000001145	0	0.000002205	47.3042	50.3738	0	0	0
Modal	LinModEigen	Mode	12	2.6756	0.00000142	0	-0.000003394	18.3352	-116.0386	0	0	0
Dead	LinStatic			0	0	145647.0098	1711952.452	-1747764	0	0	0	0
Live	LinStatic			0	0	25920	311040	-311040	0	0	0	0
EQ-X	LinStatic			-2631.6406	0	0	0	-136034.2059	27919.6786	0	0	0
EQ-Y	LinStatic			0	-2631.6406	0	136034.2059	0	-31579.6875	0	0	0
TIME HISTORY FUNCTION	LinModHist	Max		2338.906	0.0001	0	0.0002	89530.8662	29416.8534	0	0	0
TIME HISTORY FUNCTION	LinModHist	Min		-2467.1774	-0.0001	0	-0.0003	-107866.7137	-28694.7136	0	0	0
1.2DEAD+1.2LIVE+1.2EQ-X	Combination			-3157.9687	0	205880.4118	2427590.942	-2633806	33503.6143	0	0	0
1.2DEAD+1.2LIVE -1.2EQ-X	Combination			3157.9687	0	205880.4118	2427590.942	-2307324	-33503.6143	0	0	0
1.2DEAD+1.2LIVE+1.2EQ-Y	Combination			0	0	205880.4118	2427590.942	-2470565	0	0	0	0
1.2DEAD+1.2LIVE -1.2EQ-Y	Combination			0	0	205880.4118	2427590.942	-2470565	0	0	0	0

Table 4. 11 Base reaction

TABLE: Modal Participating Mass Ratios														
Case	Mode	Period	UX	UY	UZ	SumUX	SumUY	SumUZ	RX	RY	RZ	SumRX	SumRY	SumRZ
		sec												
Modal	1	2.564	0	0.784	0	0	0.784	0	0.2186	0	0	0.2186	0	0
Modal	2	1.893	0.3468	0	0	0.3468	0.784	0	0	0.041	0.4586	0.2186	0.041	0.4586
Modal	3	1.445	0.5069	0	0	0.8537	0.784	0	0	0.061	0.3586	0.2186	0.1021	0.8172
Modal	4	0.832	0	0.1069	0	0.8537	0.8908	0	0.4881	0	0	0.7066	0.1021	0.8172
Modal	5	0.761	0.023	0	0	0.8767	0.8908	0	0	0.6294	0.0064	0.7066	0.7315	0.8236
Modal	6	0.655	0.0056	0	0	0.8823	0.8908	0	0	4.32E-05	0.0619	0.7066	0.7315	0.8855
Modal	7	0.463	0	0.0359	0	0.8823	0.9268	0	0.0725	0	0	0.7792	0.7315	0.8855
Modal	8	0.453	0.0475	0	0	0.9298	0.9268	0	0	0.0374	0.0031	0.7792	0.7689	0.8886
Modal	9	0.383	0.001	0	0	0.9309	0.9268	0	0	0.0061	0.038	0.7792	0.775	0.9266
Modal	10	0.314	0	0.0196	0	0.9309	0.9463	0	0.0652	0	0	0.8443	0.775	0.9266
Modal	11	0.311	0.014	0	0	0.9448	0.9463	0	0	0.071	0.0007	0.8443	0.8459	0.9273
Modal	12	0.264	0.0017	0	0	0.9465	0.9463	0	0	0.0036	0.0165	0.8443	0.8496	0.9438

Table 4. 12 Modal participating mass ratios

4.4 Analysis of G+24 with and without Tuned Liquid Column Damper (TLCD)

Now, analysis is carried out without considering the Tuned Liquid Column

Damper as shown below:

4.3.1 3D view of building

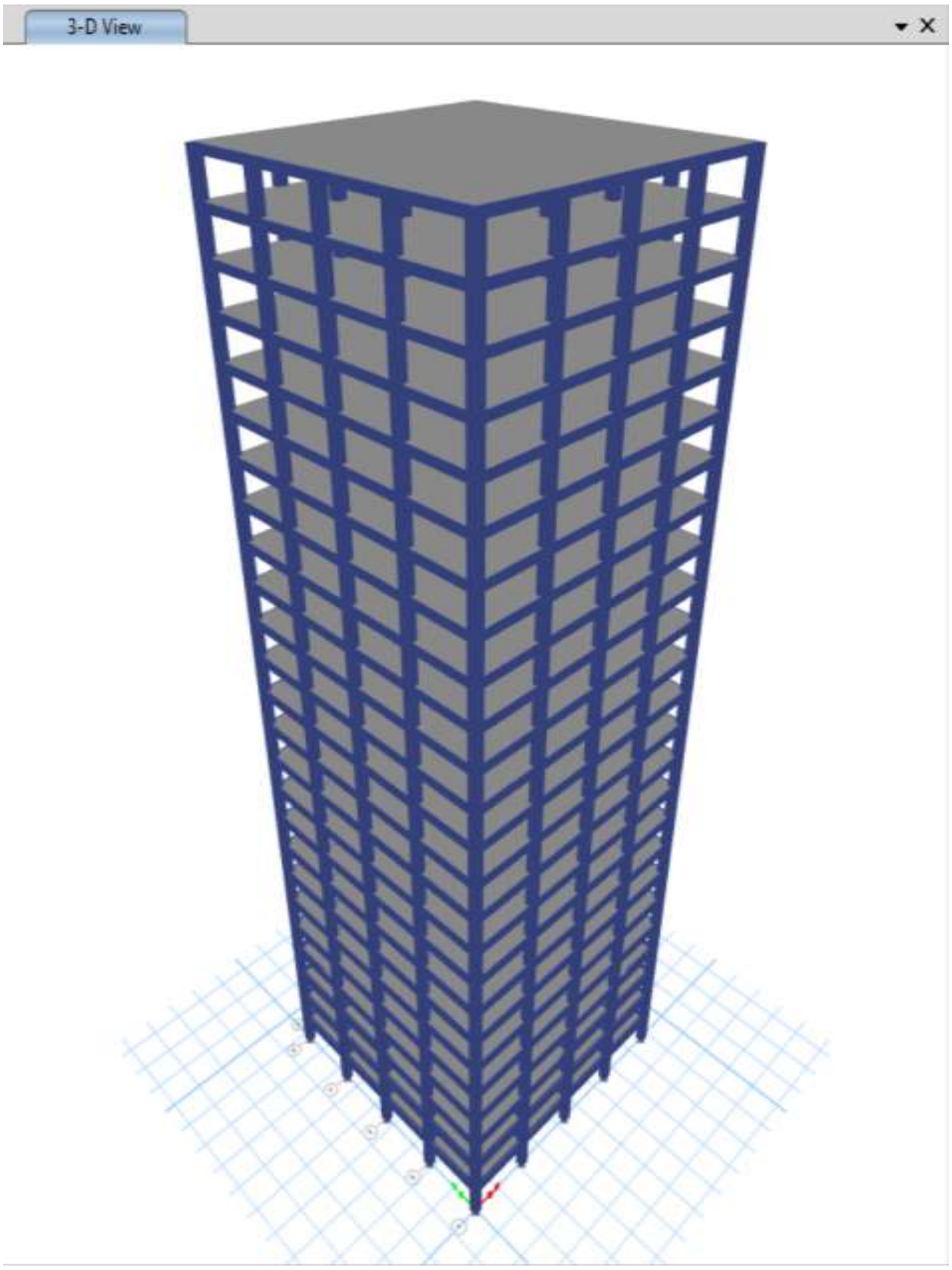


Figure 4. 10 3D view of building

4.3.5 Maximum Story Displacement

TABLE: Story Response				
Story	Elevation	Location	X-Dir	Y-Dir
	m		mm	mm
Terrace	75	Top	60.424	60.424
Story24	72	Top	59.562	59.562
Story23	69	Top	58.475	58.475
Story22	66	Top	57.142	57.142
Story21	63	Top	55.571	55.571
Story20	60	Top	53.779	53.779
Story19	57	Top	51.785	51.785
Story18	54	Top	49.61	49.61
Story17	51	Top	47.272	47.272
Story16	48	Top	44.784	44.784
Story15	45	Top	42.165	42.165
Story14	42	Top	39.432	39.432
Story13	39	Top	36.603	36.603
Story12	36	Top	33.694	33.694
Story11	33	Top	30.723	30.723
Story10	30	Top	27.704	27.704
Story9	27	Top	24.65	24.65
Story8	24	Top	21.575	21.575
Story7	21	Top	18.492	18.492
Story6	18	Top	15.412	15.412
Story5	15	Top	12.348	12.348
Story4	12	Top	9.319	9.319
Story3	9	Top	6.361	6.361
Story2	6	Top	3.568	3.568
Story1	3	Top	1.199	1.199
Base	0	Top	0	0

Table 4. 13 Maximum Story Displacement

4.3.6 Analysis of G+24 building with TLCD

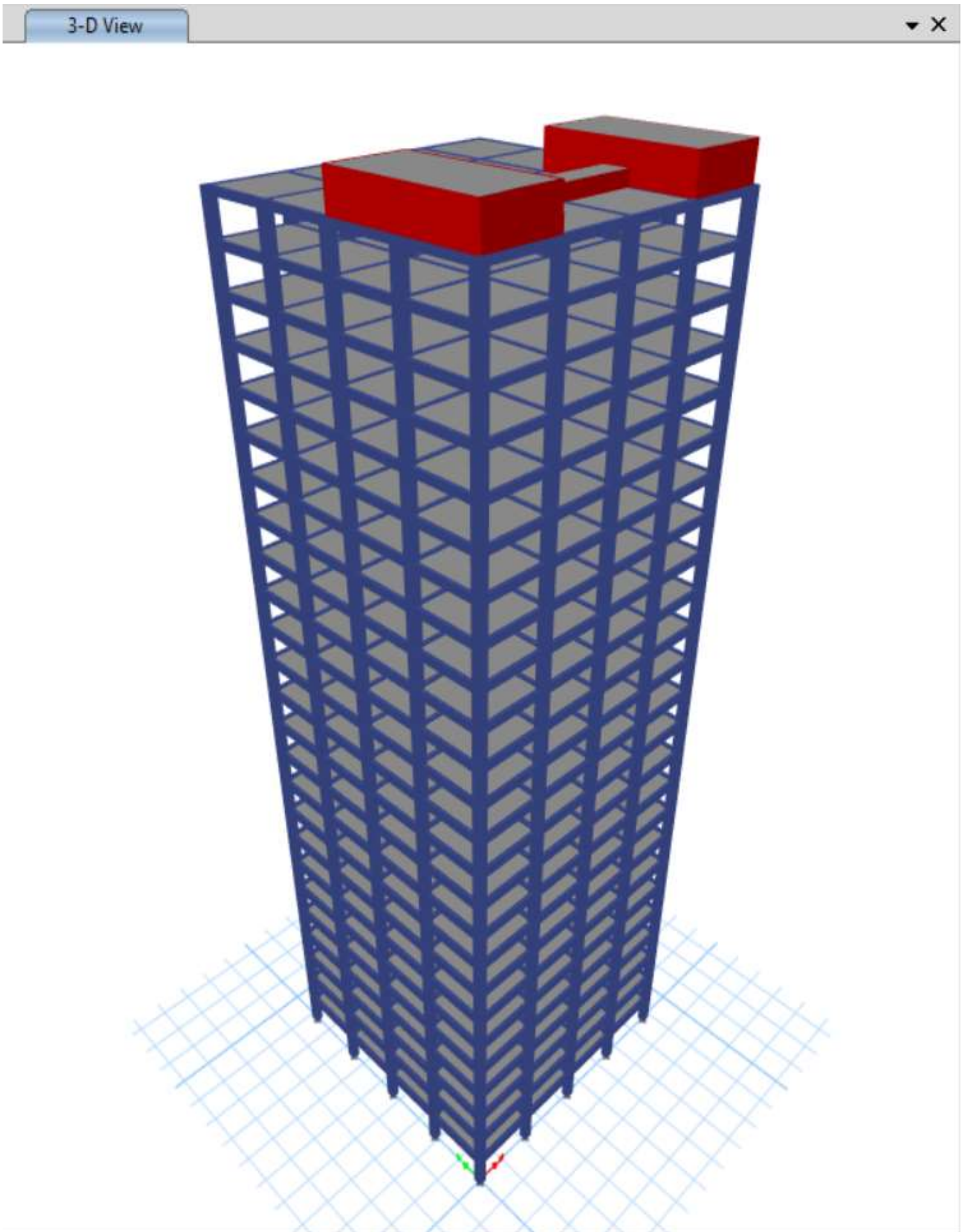


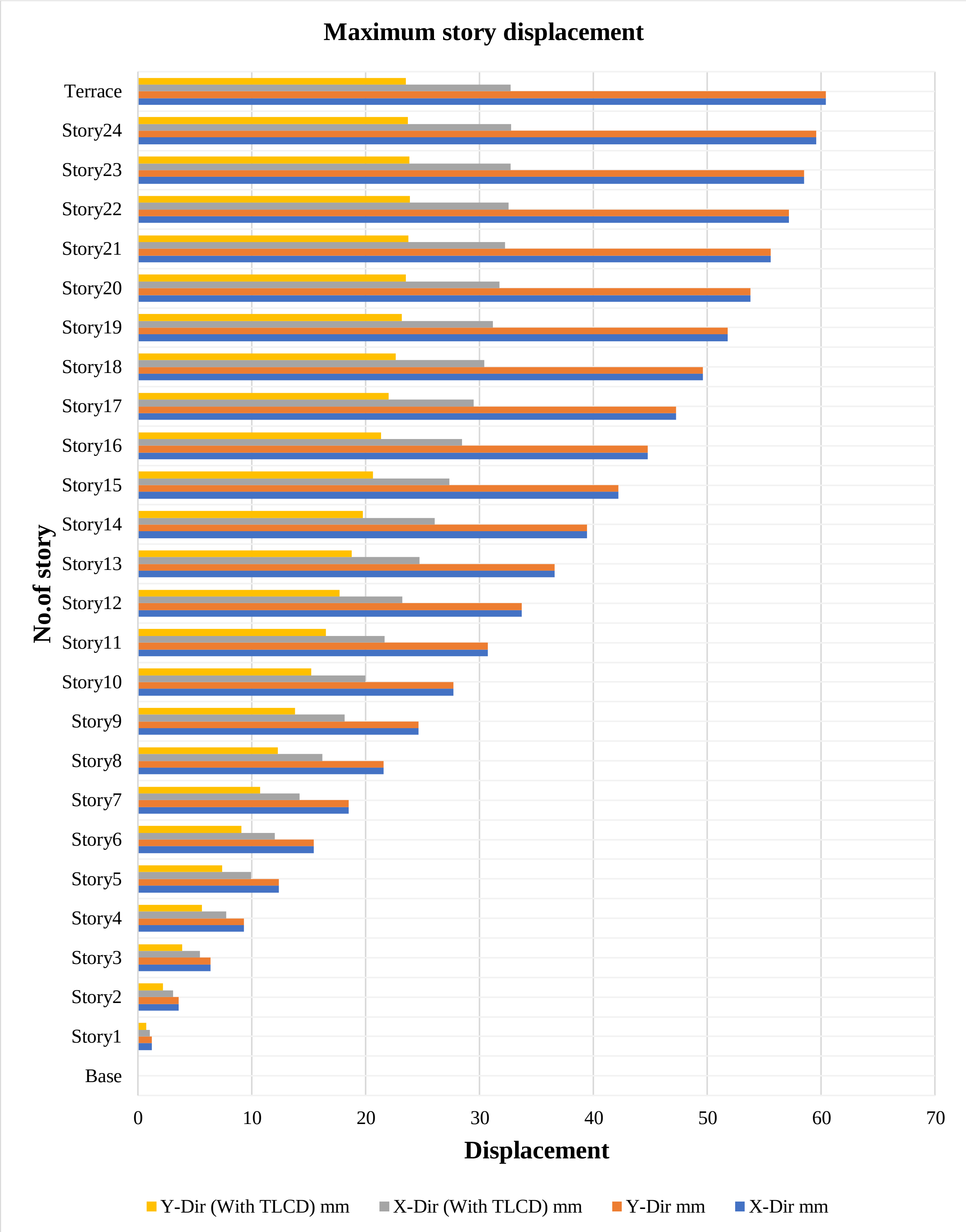
Figure 4. 11 G+24 building with TLCD (3D View)

4.3.7 Maximum Story Displacement

TABLE: Story Response				
Story	Elevation	Location	X-Dir	Y-Dir
	m		mm	mm
Terrace	75	Top	32.734	23.51
Story24	72	Top	32.755	23.695
Story23	69	Top	32.712	23.834
Story22	66	Top	32.538	23.866
Story21	63	Top	32.22	23.763
Story20	60	Top	31.755	23.521
Story19	57	Top	31.142	23.146
Story18	54	Top	30.389	22.637
Story17	51	Top	29.497	21.997
Story16	48	Top	28.474	21.359
Story15	45	Top	27.329	20.616
Story14	42	Top	26.072	19.753
Story13	39	Top	24.703	18.775
Story12	36	Top	23.225	17.688
Story11	33	Top	21.641	16.491
Story10	30	Top	19.944	15.189
Story9	27	Top	18.131	13.786
Story8	24	Top	16.205	12.291
Story7	21	Top	14.168	10.716
Story6	18	Top	12.032	9.071
Story5	15	Top	9.928	7.368
Story4	12	Top	7.731	5.628
Story3	9	Top	5.412	3.88
Story2	6	Top	3.095	2.192
Story1	3	Top	1.053	0.739
Base	0	Top	0	0

Table 4. 14 Maximum Story Displacement

Maximum story displacement for G+24 building



Graph 4. 4 Maximum story displacement for G+24 building

Base reaction and Modal participating mass ratios for G+24 building (With TLCD)

TABLE: Base Reactions													
Output Case	Case Type	Step Type	Step Number	Step Label	FX	FY	FZ	MX	MY	MZ	X	Y	Z
					kN	kN	kN	kN-m	kN-m	kN-m	m	m	m
Modal	LinModEigen	Mode	1		0	-0.447	0	24.3466	0	-5.3642	0	0	0
Modal	LinModEigen	Mode	2		-0.5802	0	0	0	-28.9996	13.4311	0	0	0
Modal	LinModEigen	Mode	3		-1.223	0	0	0	-60.6613	3.4174	0	0	0
Modal	LinModEigen	Mode	4		0	1.6212	0	10.894	0	19.4549	0	0	0
Modal	LinModEigen	Mode	5		-0.8433	0	0	0	75.5435	15.5583	0	0	0
Modal	LinModEigen	Mode	6		0.6071	0	0	0	31.6941	-26.7682	0	0	0
Modal	LinModEigen	Mode	7		-0.000006494	-2.8861	0	25.6502	-0.000009822	-34.6328	0	0	0
Modal	LinModEigen	Mode	8		3.5938	0	0	0	83.9264	-31.367	0	0	0
Modal	LinModEigen	Mode	9		-0.6819	-0.000002322	0	0.000002961	14.4091	53.0053	0	0	0
Modal	LinModEigen	Mode	10		-0.000001815	-4.6412	0	-1.7203	-0.000008254	-55.6949	0	0	0
Modal	LinModEigen	Mode	11		3.9398	-6.821E-07	0	0.000001904	-47.0759	-36.0737	0	0	0
Modal	LinModEigen	Mode	12		2.0151	6.841E-07	0	0.000001271	19.2943	-83.9556	0	0	0
Dead	LinStatic				0	0	173727.286	2041753.422	-2084727	0	0	0	0
Live	LinStatic				0	0	31104	373248	-373248	0	0	0	0
EQ-X	LinStatic				-3139.1067	0	0	0	-193068.1861	33263.6267	0	0	0
EQ-Y	LinStatic				0	-3139.1067	0	193068.1861	0	-37669.2804	0	0	0
TIME HISTORY FUNCTION	LinModHist	Max			2207.3371	0.0001	0	0.0001	100912.6264	26628.1867	0	0	0
TIME HISTORY FUNCTION	LinModHist	Min			-2061.0085	-0.0001	0	-0.0001	-108760.976	-29696.745	0	0	0
1.2DEAD+1.2LIVE+1.2EQ-X	Combination	Max			0	0	245797.5432	3129683.529	-2949571	39916.352	0	0	0
1.2DEAD+1.2LIVE+1.2EQ-X	Combination	Min			-3766.928	-3766.928	245797.5432	2898001.706	-3181252	-45203.1365	0	0	0
1.2DEAD+1.2LIVE -1.2EQ-X	Combination	Max			3766.928	3766.928	245797.5432	2898001.706	-2717889	45203.1365	0	0	0
1.2DEAD+1.2LIVE -1.2EQ-X	Combination	Min			0	0	245797.5432	2666319.883	-2949571	-39916.352	0	0	0
1.2DEAD+1.2LIVE+1.2EQ-Y	Combination				0	0	245797.5432	2898001.706	-2949571	0	0	0	0
1.2DEAD+1.2LIVE -1.2EQ-Y	Combination				0	0	245797.5432	2898001.706	-2949571	0	0	0	0

Table 4. 15 Base reaction

TABLE: Modal Participating Mass Ratios														
Case	Mode	Period	UX	UY	UZ	SumUX	SumUY	SumUZ	RX	RY	RZ	SumRX	SumRY	SumRZ
		sec												
Modal	1	3.123	0	0.781	0	0	0.781	0	0.2211	0	0	0.2211	0	0
Modal	2	2.241	0.3489	0	0	0.3489	0.781	0	0	0.0402	0.4584	0.2211	0.0402	0.4584
Modal	3	1.695	0.5067	0	0	0.8556	0.781	0	0	0.0529	0.3605	0.2211	0.0931	0.8189
Modal	4	1.006	0	0.1106	0	0.8556	0.8915	0	0.4856	0	0	0.7067	0.0931	0.8189
Modal	5	0.91	0.02	0	0	0.8756	0.8915	0	0	0.6402	0.0094	0.7067	0.7333	0.8284
Modal	6	0.782	0.0057	0	0	0.8813	0.8915	0	0	0.0011	0.0577	0.7067	0.7344	0.8861
Modal	7	0.564	0	0.0347	0	0.8813	0.9263	0	0.0706	0	0	0.7773	0.7344	0.8861
Modal	8	0.55	0.0485	0	0	0.9298	0.9263	0	0	0.0314	0.0034	0.7773	0.7658	0.8894
Modal	9	0.463	0.0009	0	0	0.9307	0.9263	0	0	0.0065	0.037	0.7773	0.7723	0.9265
Modal	10	0.385	0	0.0195	0	0.9307	0.9457	0	0.0647	0	0	0.8419	0.7723	0.9265
Modal	11	0.38	0.0133	0	0	0.944	0.9457	0	0	0.0718	0.0007	0.8419	0.844	0.9271
Modal	12	0.323	0.0018	0	0	0.9458	0.9457	0	0	0.0035	0.0158	0.8419	0.8476	0.943

Table 4. 16 Modal participating mass ratios

4.4.1 El-Centro earthquake (G+24)

(a) Combined Story Response Plot for 2% of the structural mass.

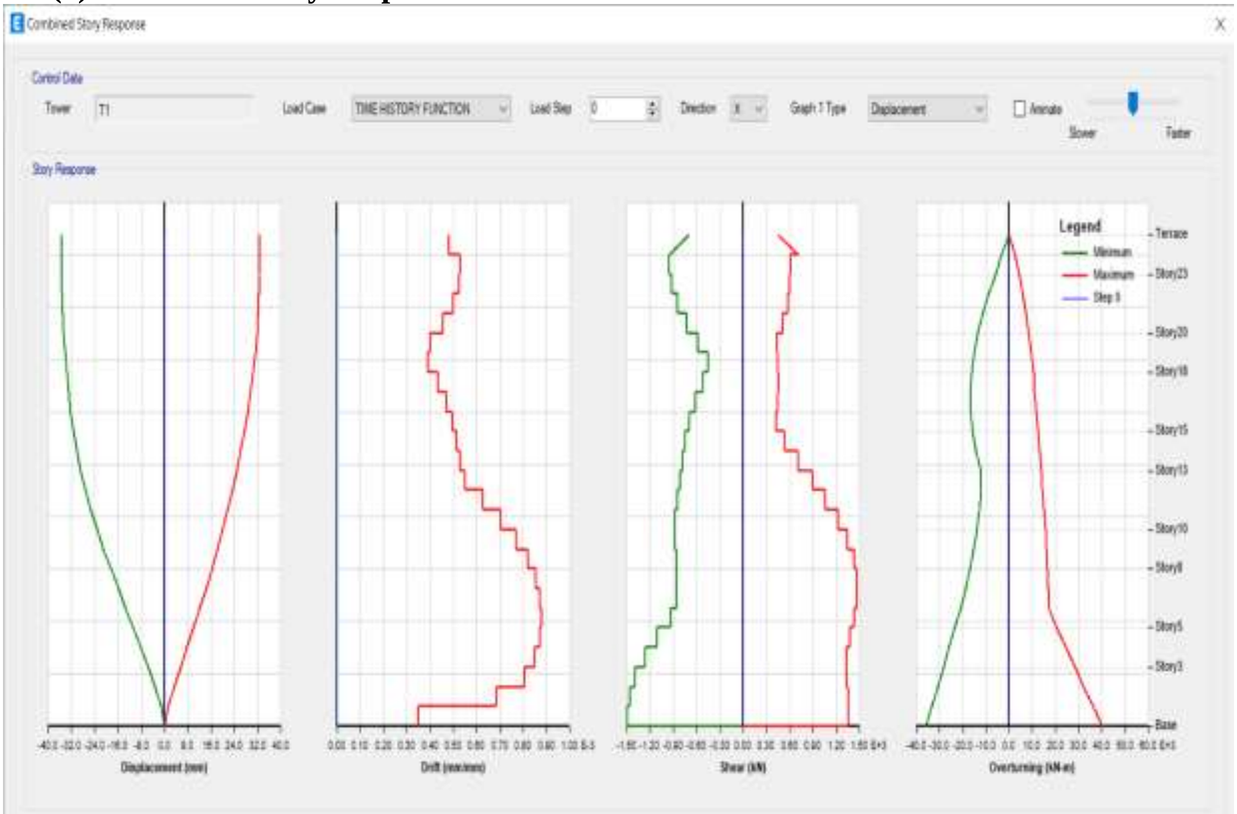
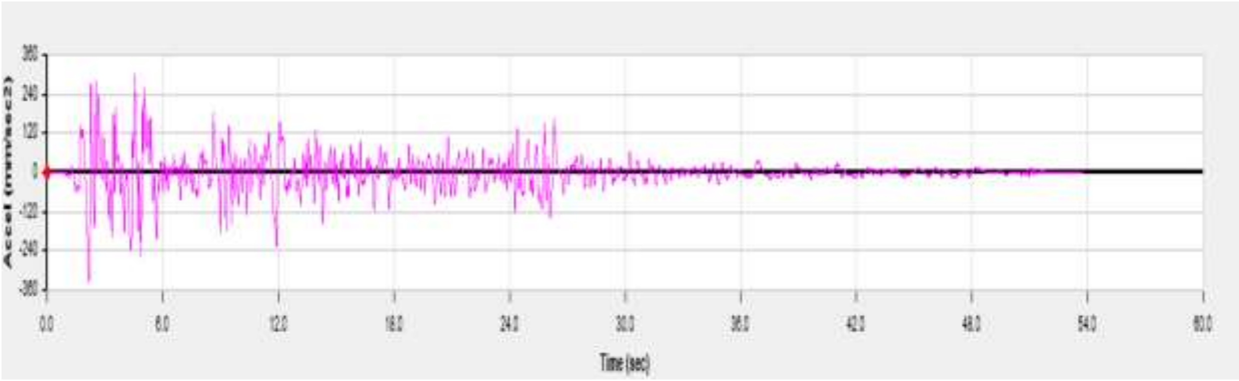


Figure 4. 12 Combined Story Response

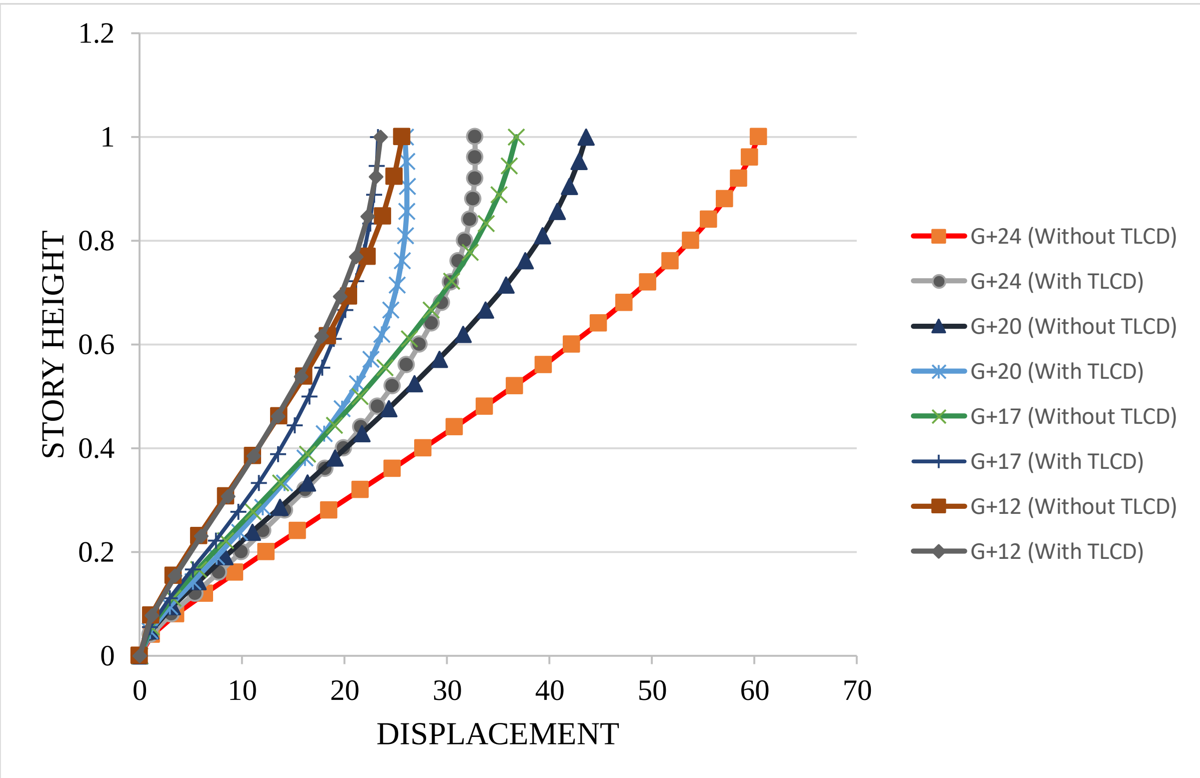
(b) Acceleration (mm/sec^2) vs Time (sec) Graph:



Graph 4. 5 El-Centro earthquake

Displacement data of different buildings											
G+12			G+17			G+20			G+24		
Story height	Without TLCD	With TLCD	Story height	Without TLCD	With TLCD	Story height	Without TLCD	With TLCD	Story height	Without TLCD	With TLCD
0	0	0	0	0	0	0	0	0	0	0	0
0.07692	1.104	1.165	0.05556	1.084	0.995	0.04762	1.073	0.999	0.04000	1.199	1.053
0.15385	3.27	3.428	0.11111	3.219	2.937	0.09524	3.19	2.95	0.08000	3.568	3.095
0.23077	5.794	6	0.16667	5.724	5.166	0.14286	5.679	5.197	0.12000	6.361	5.412
0.30769	8.421	8.594	0.22222	8.36	7.425	0.19048	8.306	7.497	0.16000	9.319	7.731
0.38462	11.045	11.105	0.27778	11.035	9.598	0.23810	10.985	9.764	0.20000	12.348	9.928
0.46154	13.605	13.486	0.33333	13.712	11.626	0.28571	13.681	11.969	0.24000	15.412	12.032
0.53846	16.055	15.713	0.38889	16.363	13.466	0.33333	16.374	14.095	0.28000	18.492	14.168
0.61538	18.345	17.761	0.44444	18.969	15.094	0.38095	19.047	16.12	0.32000	21.575	16.205
0.69231	20.424	19.578	0.50000	21.505	16.522	0.42857	21.685	18.01	0.36000	24.65	18.131
0.76923	22.235	21.101	0.55556	23.949	17.777	0.47619	24.272	19.731	0.40000	27.704	19.944
0.84615	23.724	22.264	0.61111	26.274	18.945	0.52381	26.79	21.25	0.44000	30.723	21.641
0.92308	24.85	23.045	0.66667	28.451	20.077	0.57143	29.22	22.552	0.48000	33.694	23.225
1	25.62	23.506	0.72222	30.451	21.082	0.61905	31.542	23.633	0.52000	36.603	24.703
			0.77778	32.242	21.883	0.66667	33.732	24.493	0.56000	39.432	26.072
			0.83333	33.789	22.463	0.71429	35.769	25.143	0.60000	42.165	27.329
			0.88889	35.063	22.861	0.76190	37.627	25.606	0.64000	44.784	28.474
			0.94444	36.044	23.114	0.80952	39.282	25.91	0.68000	47.272	29.497
			1	36.753	23.264	0.85714	40.712	26.074	0.72000	49.61	30.389
						0.90476	41.903	26.112	0.76000	51.785	31.142
						0.95238	42.845	26.04	0.80000	53.779	31.755
						1	43.558	25.918	0.84000	55.571	32.22
									0.88000	57.142	32.538
									0.92000	58.475	32.712
									0.96000	59.562	32.755
									1	60.424	32.734

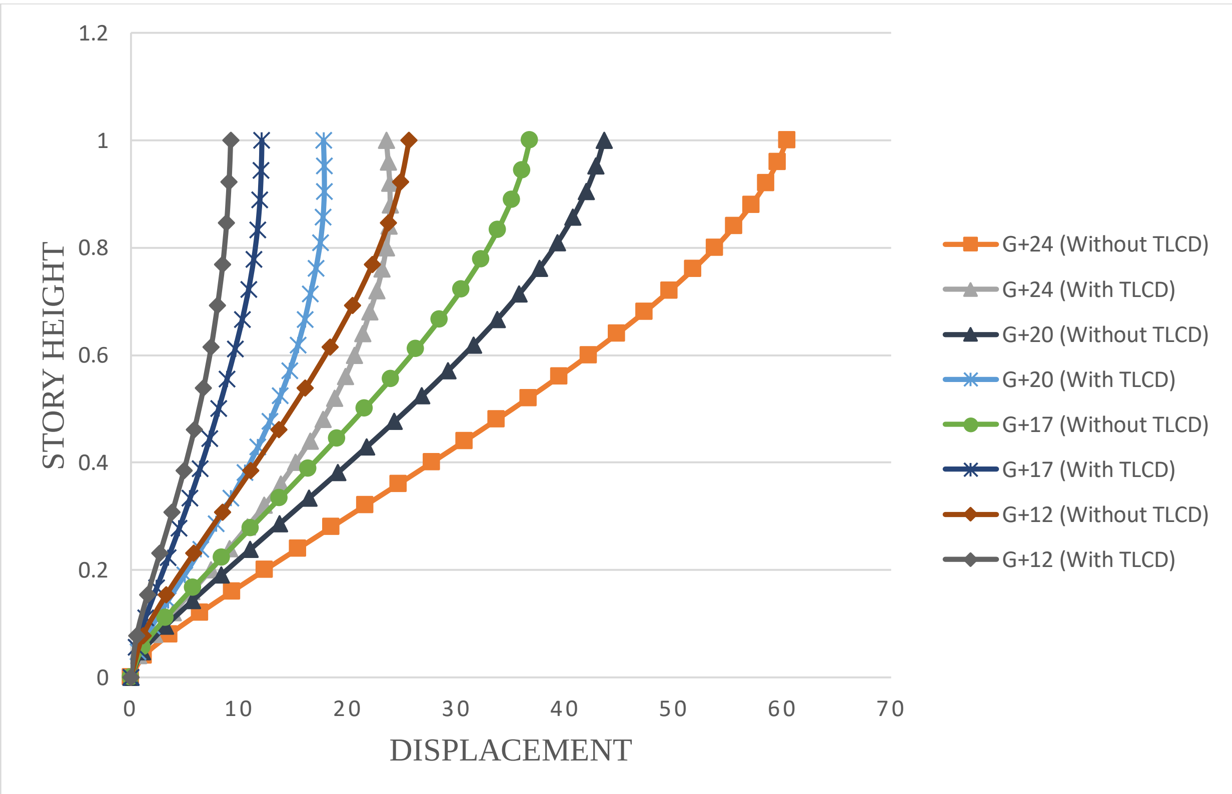
Table 4. 17 Displacements of different Buildings at different Storey Heights in the direction of X for EQ-X



Graph 4. 6 Comparison of Displacements of different Buildings at different Storey Heights in the direction of X for EQ-X

Displacement data of different buildings											
G+12			G+17			G+20			G+24		
Story height	Without TLCD	With TLCD	Story height	Without TLCD	With TLCD	Story height	Without TLCD	With TLCD	Story height	Without TLCD	With TLCD
0	0	0	0	0	0	0	0	0	0	0	0
0.07692	1.104	0.521	0.05556	1.084	0.456	0.04762	1.073	0.656	0.04000	1.199	0.739
0.15385	3.27	1.531	0.11111	3.219	1.349	0.09524	3.19	1.94	0.08000	3.568	2.192
0.23077	5.794	2.676	0.16667	5.724	2.378	0.14286	5.679	3.422	0.12000	6.361	3.88
0.30769	8.421	3.813	0.22222	8.36	3.43	0.19048	8.306	4.942	0.16000	9.319	5.628
0.38462	11.045	4.88	0.27778	11.035	4.461	0.23810	10.985	6.435	0.20000	12.348	7.368
0.46154	13.605	5.846	0.33333	13.712	5.447	0.28571	13.681	7.872	0.24000	15.412	9.071
0.53846	16.055	6.69	0.38889	16.363	6.378	0.33333	16.374	9.235	0.28000	18.492	10.716
0.61538	18.345	7.4	0.44444	18.969	7.254	0.38095	19.047	10.513	0.32000	21.575	12.291
0.69231	20.424	7.977	0.50000	21.505	8.077	0.42857	21.685	11.699	0.36000	24.65	13.786
0.76923	22.235	8.464	0.55556	23.949	8.86	0.47619	24.272	12.784	0.40000	27.704	15.189
0.84615	23.724	8.818	0.61111	26.274	9.594	0.52381	26.79	13.762	0.44000	30.723	16.491
0.92308	24.85	9.047	0.66667	28.451	10.261	0.57143	29.22	14.631	0.48000	33.694	17.688
1	25.62	9.188	0.72222	30.451	10.838	0.61905	31.542	15.386	0.52000	36.603	18.775
			0.77778	32.242	11.307	0.66667	33.732	16.022	0.56000	39.432	19.753
			0.83333	33.789	11.656	0.71429	35.769	16.535	0.60000	42.165	20.616
			0.88889	35.063	11.885	0.76190	37.627	17.046	0.64000	44.784	21.359
			0.94444	36.044	12.006	0.80952	39.282	17.443	0.68000	47.272	21.997
			1	36.753	12.065	0.85714	40.712	17.695	0.72000	49.61	22.637
						0.90476	41.903	17.811	0.76000	51.785	23.146
						0.95238	42.845	17.801	0.80000	53.779	23.521
						1	43.558	17.73	0.84000	55.571	23.763
									0.88000	57.142	23.866
									0.92000	58.475	23.834
									0.96000	59.562	23.695
									1	60.424	23.51

Table 4. 18 Displacements of different Buildings at different Storey Heights in the direction of Y for EQ-Y



Graph 4. 7 Comparison of Displacements of different Buildings at different Storey Heights in the direction of Y for EQ-Y

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

5.1 Conclusion

The following results may be drawn from this research or study:

a) The study on TLCDs demonstrates that they may be utilised to reduce structural reaction during seismic activity.

b) A well designed TLCD, using effective design parameters like depth ratio, damping ratio, and mass ratio is a highly successful approach in minimising structural response from this study.

c) Non-TLCD structures are more prone to displacement than TLD structures.

d) The structure analysis indicated that the TLCD can effectively track structural vibrations even without this study.

e) The TLCD effect is only significant in seismic zones with strong resonance. To put it another way, TLCD has been proven to be most optimal for enhancing resonant violent shaking of structures. TLCD, on the other hand, has almost no influence in the low-resonance seismic zone.ss

f) From the above study, it can be analysed that 2% to 5% of the total structural mass is used as TMD to reduce structural reaction during seismic activity.

5.2 Future Scope of the work

1. The analysis of irregular buildings with various irregularities will be carried out.
2. The study could be modified to include other tank geometries.
3. Different types of infill and different heights will be analyzed.
4. Different other software will be used to do the analysis.
5. Shaking table tests can be used for experimental work.

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