Int.J.HIT.TRANSC:ECCN.Vol.7: Issue 2A (2021) Page 1-11 ISSN: 0973-6875

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ORIGINAL CONTRIBUTION

A Parametric Study on Response Control of Building Using Tuned Liquid Damper

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ABSTRACT

The performance of Tuned Liquid Damper (TLD) to mitigate the seismic vibration of structures under different real earthquake time history is investigated in the present study.The effectiveness of a tuned liquid damper (TLD) is demonstrated in this paper. TLD structural vibration can be used in the construction of damp structures. A tuned liquid damper is water contained in a container, usually placed on top of a building that uses the water's sloshing power to reduce the system's dynamic response to stress.Tuning is the frequency of TLD to the fundamental frequency of structure will result in a large amount of energy dissipation. Most of the researches have studied using TLD on controlling the response of structures under wind loads. Herein, a MDOF system is analysed for determining the displacement of the structure using Newmark Beta method with the help of MATLAB coding, considering a standard model of single tuned liquid damper.

Keywords: Vibration control, Tuned liquid Damper, Newmark Beta method

1. INTRODUCTION

Recently, due to limited space in urban area, economic requirements and advanced construction techniques have caused an increased the tall buildings. Theses tall buildings have become relatively lighter, flexible and low inherent damping due to use of high strength materials. These tall buildings are more vulnerable due to environment hazards such as wind and earthquake loadings. The occupants, especially in the upper floors of the tall buildings are feeling discomfort due to vibration caused by such type of loadings. Passive vibration control devices like, Tuned liquid column damper(TLCD), Liquid column vibration absorber(LCVA), Tuned mass damper(TMD),Tuned liquid damper(TLD) and base isolation (BI) system are capable to reduce earthquake or wind induced vibrations. Tuned liquid damper (TLD) has increased in more popularity due to its low implementation and maintenance cost. TLD dissipates energy through viscous action of liquid, wave breaking, contamination of the free surface. The natural frequency of TLD is tuned to the fundamental natural frequency of structure. To understand the behavior of structure due to earthquake excitations various types of real earthquake are considered, such as Chamoli, El Centro, Lomaprieta and Parkfield. The specific objectives of the study are: (a) to present the mathematical formulations for evaluation of response of undamped MDOF structures and structure having TLD at top, (b) to evaluate and compare the displacement of the structure subjected to the mentioned cases, and (c) to study the effects of important system parameters on the variation of response of structure.

2. FORMULATIONOF TUNED LIQUID DAMPER

A rectangular Tuned Liquid Damper (TLD) is a passive vibration control device, which is used to mitigate the structural vibrations due to seismic loads or wind loads. It dissipates energy through liquid boundary layer friction, the free contamination and wave breaking. Tuned liquid

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dampers could be designed and implemented easily due to its low cost and maintenance and liquid is used as water. The natural frequency of a rectangular water tank can be calculated as, (Yu et al., 1999)

$$f_{\omega} = \frac{1}{2\pi}\sqrt{\frac{\pi g}{L}\tanh\left(\frac{\pi h}{L}\right)} \qquad (1)$$

Where,

L= Length of water tank.

h= Height of water in the rectangular tank

g= Acceleration due to gravity

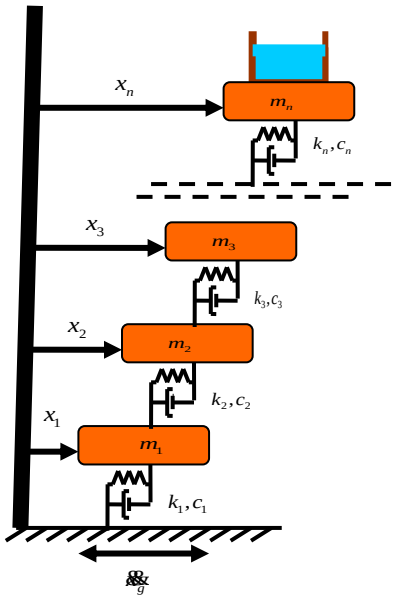


Figure 1: MDOF structure with TLD system

The equation of motion of a MDOF system attached with TLD (as shown in Fig.1) can be expressed as

$$\hat{\mathbf{M}}\ddot{\mathbf{X}} + \hat{\mathbf{C}}\dot{\mathbf{X}} + \hat{\mathbf{K}}\mathbf{X} = -\hat{\mathbf{M}}\bar{\mathbf{r}}\ddot{x}_g \qquad (2)$$

Where, $\mathbf{Y} = [x_s, x_1, x_2, ..., x_n]^T$ is the relative displacement vector, and $\bar{\mathbf{r}} = [0 \quad \mathbf{I}]^T$, where **I**is an nx1 unit vector. $\hat{\mathrm{M}}, \hat{\mathrm{C}}$ and $\hat{\mathrm{K}}$ Represent the mass, damping and stiffness matrix of the combined system.

$$\hat{M} = \begin{bmatrix} m_{s1} & 0 & \dots & \dots & \dots & \dots & 0 \\ 0 & m_{s2} & \dots & \dots & \dots & \dots & 0 \\ \dots & \dots & m_{s3} & \dots & \dots & \dots & \dots \\ \text{M} & \text{M} & \text{M} & \text{O} & \text{M} & \text{M} & \text{M} \\ \dots & \dots & \dots & \dots & m_{sn-1} & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots & m_{sn} & 0 \\ 0 & 0 & \dots & \dots & \dots & 0 & m_d \end{bmatrix}$$

$$\hat{K} = \begin{bmatrix} k_1+k_2 & -k_2 & 0 & \dots & \dots & \dots & 0 \\ -k_2 & k_2+k_3 & -k_3 & \dots & \dots & \dots & 0 \\ 0 & -k_3 & k_3+k_4 & \dots & \dots & \dots & \dots \\ \text{M} & \text{M} & \text{M} & \text{O} & \text{M} & \text{M} & \text{M} \\ \dots & \dots & \dots & -k_{n-1} & k_{n-1}+k_n & -k_n & \dots \\ \dots & \dots & \dots & \dots & -k_n & k_n+k_d & -k_d \\ 0 & 0 & \dots & \dots & \dots & -k_d & k_d \end{bmatrix}$$

$$C_s = \alpha_1 M_s + \alpha_2 K_s \tag{3}$$

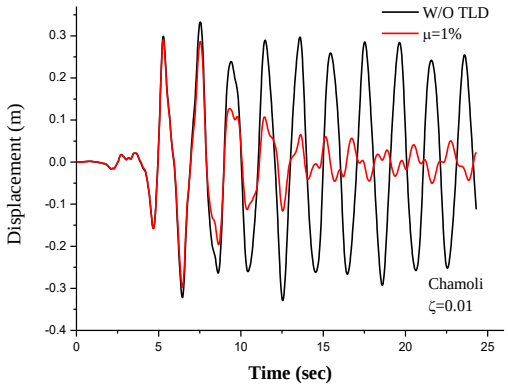
The damping matrix C_s can be determined by using the Equation (3) and the algorithm developed based on Newmark Beta method, the value of α_1 and α_2 are the constants derived using the damping ratio. The values of constants on Newmark Beta method are $\alpha = 0.25$ and $\beta = 0.5$.

3. NUMERICAL STUDY

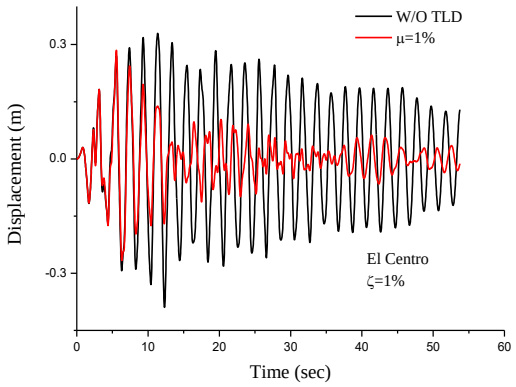
A 10-storied building with TLD subjected to real earthquake time history data is undertaken to study the performance of the proposed TLD. The building has the following mass and stiffness values: $m_1 = m_2 = m_3 = m_4 = 136.2 \times 10^3$ kg, $m_5 = 126.40 \times 10^3$ kg , $k_1 = k_2 = 415.46 \times 10^6$ N/m , $k_3 = k_4 = k_5 = 415.46 \times 10^6$ N/m . Unless mentioned otherwise, following nominal values are assumed for various parameters: damping ratio of structures, $\xi_s = 1\%$ and 2%, mass ratio, $\mu = 1\%$. The fundamental natural frequency of the building is f_1 = 0.49453 Hz. The frequency of TLD is tuned based on the fundamental frequency of building. Assume, depth ratio (r), $\left(\frac{h}{L}\right) = 0.53$ and the length of water tank =2.97 m. The height of water tank is calculated from Equation (1).

4. RESULTS AND DISCUSSION

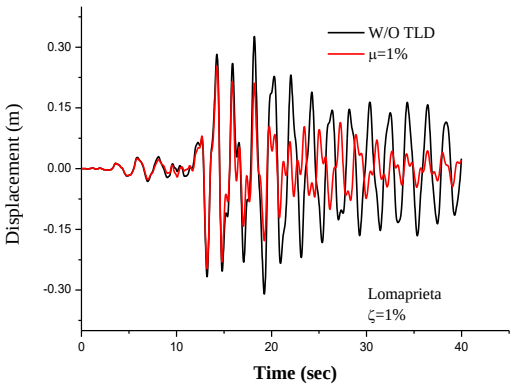
The variation of displacements of structures with time considering time history data of Chamoli, EL Centro, Loma Prieta and Park Field earthquake for different damping ratio of structure are shown in Figures2 and 3. It is observed that TLD is performed more effectively when it is installed at the structure having low damping ratio. The percent reduction of top storey displacement of structures($\zeta = 1\%$), like, 10.63%, 26.83%, 22.42% and 24.13% for Chamoli, EL Centro, Lomaprieta and Parkfield earthquake using TLD system. The displacement reductions are observed within the duration 10-15 sec for El Centro and 5-7 sec for Chamoli earthquake.



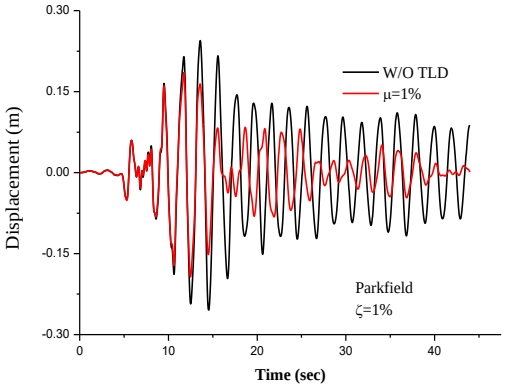
(a) Chamoli earthquake



(b) El Centro earthquake

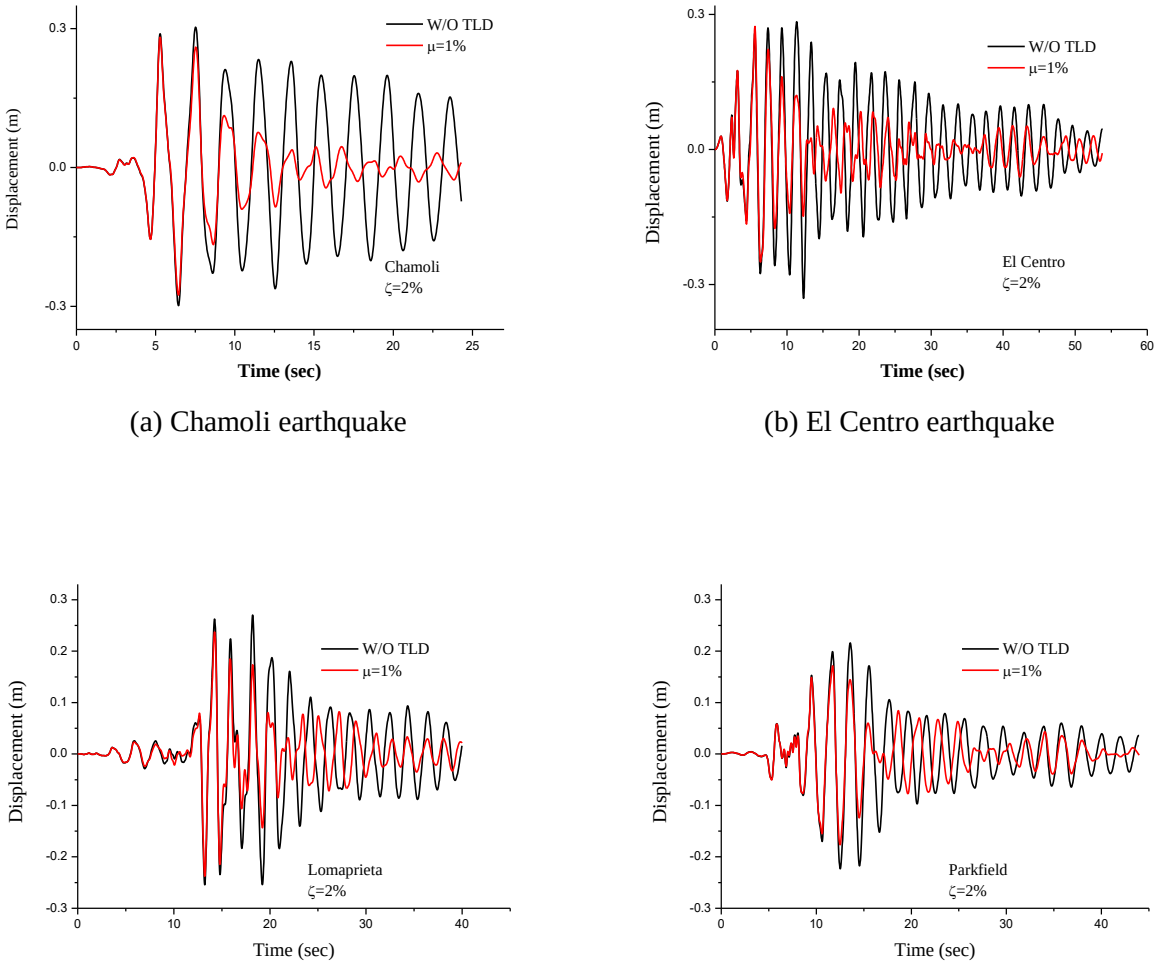


(c) Lomaprieta earthquake



(d) Parkfield earthquake.

Figure 2: Variation of displacement of structures with time for 1% damping ratio of structures considering different real earthquake accelerograms, (a)-(d).



(a) Chamoli earthquake

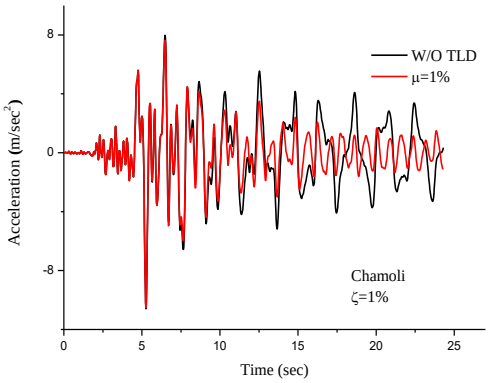
(b) El Centro earthquake

(c) Lomaprieta earthquake

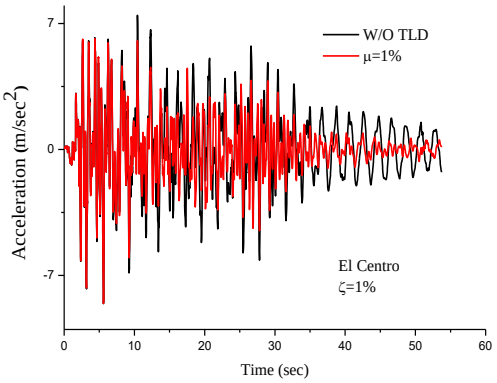
(d) Parkfield earthquake.

Figure3: Variation of displacement of structures with time for 2% damping ratio of structures considering different real earthquake accelerograms, (a)-(d).

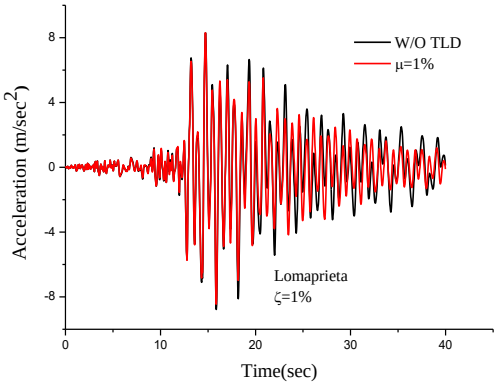
The variation of accelerations at top storey of building with time considering time history data Chamoli, El Centro, Lomaprieta and Parkfield earthquake for 1% mass ratio and 1-2% damping ratio of structure are shown in Figure4 and 5. It can be observed that maximum accelerations occurred during 5-7 sec for Chamoli earthquake, 5-15 sec for El Centro earthquake, 12-15 sec for Lomapriera and 7-12sec for park field earthquake.



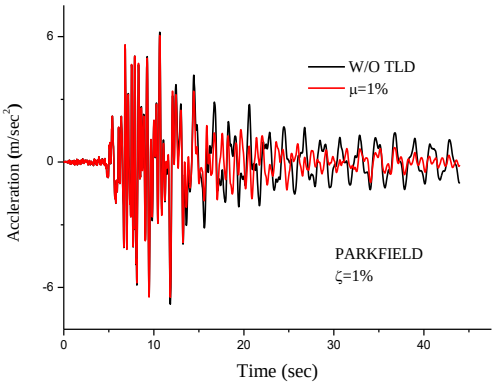
(a) Chamoli earthquake



(b) El Centro earthquake

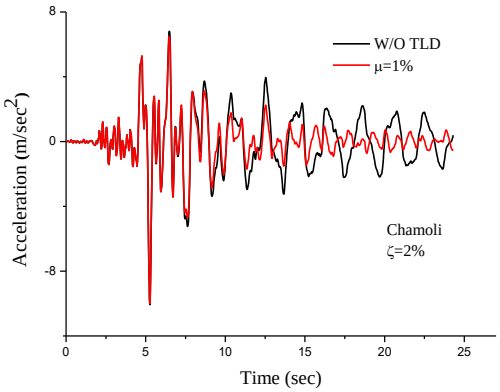


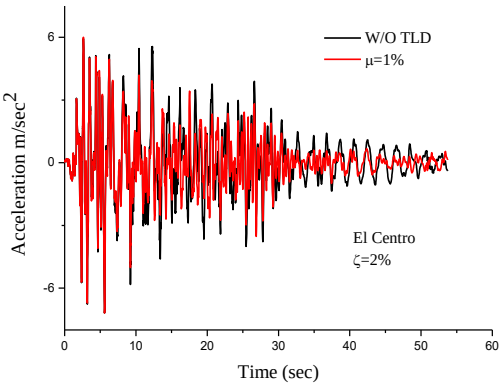
(c) Lomaprieta earthquake



(d) Parkfield earthquake.

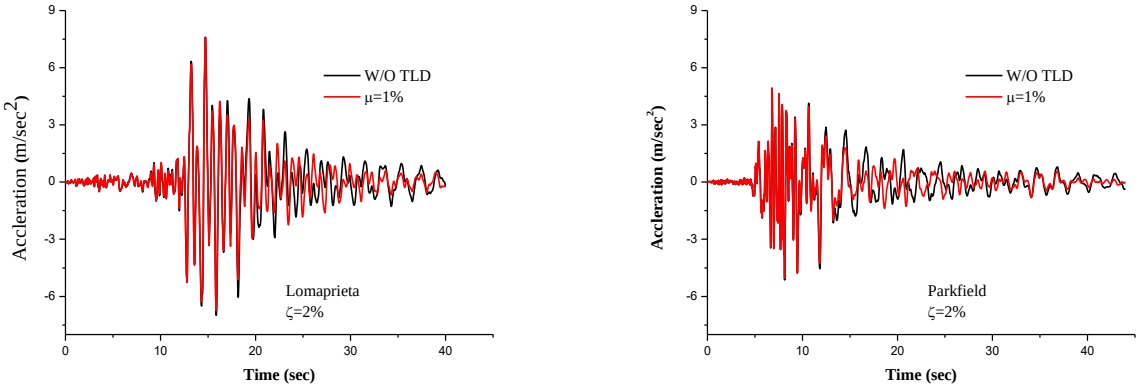
Figure 4: Variation of accelerations of structures with time for 1% mass ratio and 1% damping ratio of structures considering different real earthquake accelerograms,(a)-(d).





(a) Chamoli earthquake

(b) El Centro earthquake

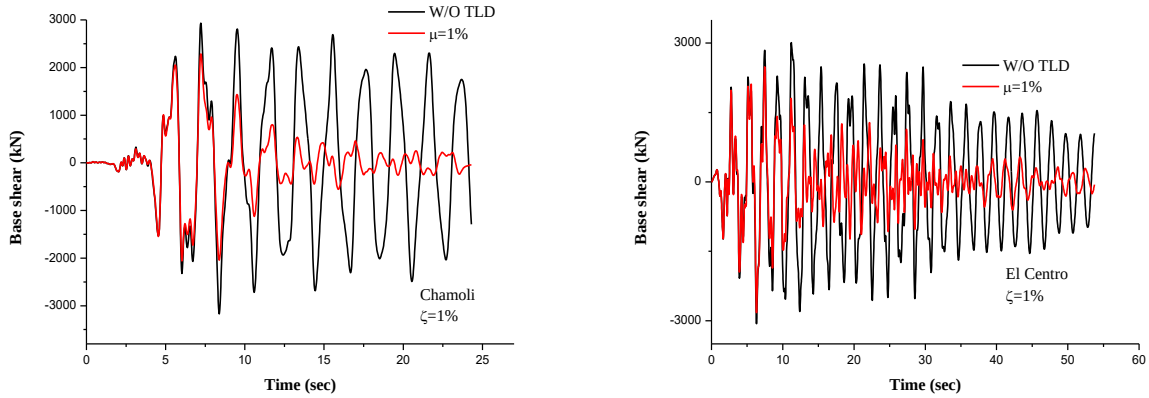


(c) Lomaprieta earthquake

(d) Parkfield earthquake

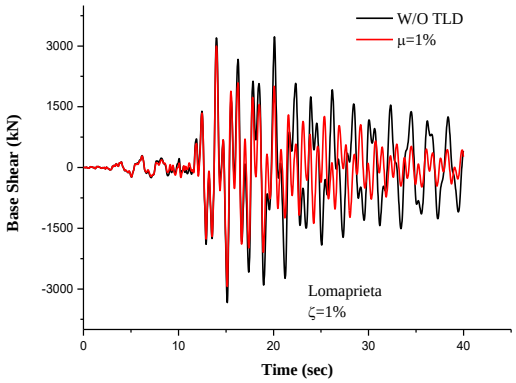
Figure 5 : Variation of accelerations of structures with time for 1% mass ratio and 2% damping ratio of structures considering different real earthquake accelerograms, (a)-(d).

The Base shears of building with time considering time history data Chamoli, El Centro, Lomaprieta and Parkfield earthquake for 1% mass ratio and 1-2% damping ratio of structure are shown in Figure6 and 7. The percent reduction of Base shears of building is observed 7-17% when structural damping(ζ) is 1% and 5-15% when structural damping is 2% for Chamoli, EL Centro, Lomaprieta and Parkfield earthquake using TLD system.

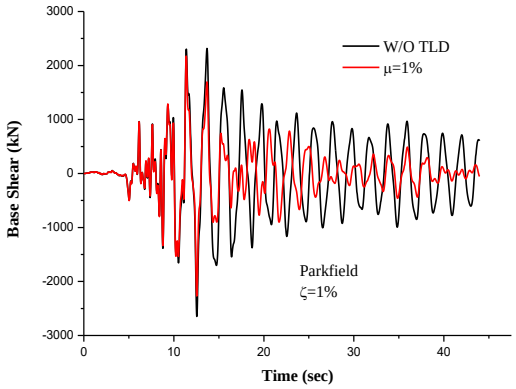


(a) Chamoli earthquake

(b) El Centro earthquake

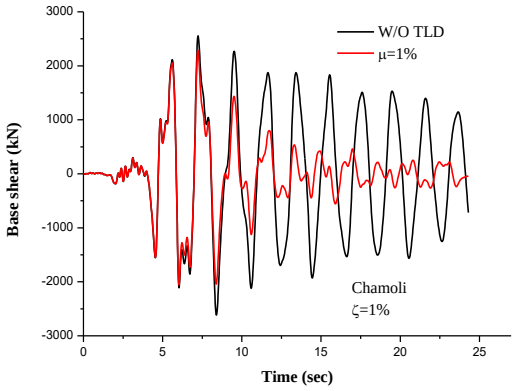


(c) Lomaprieta earthquake

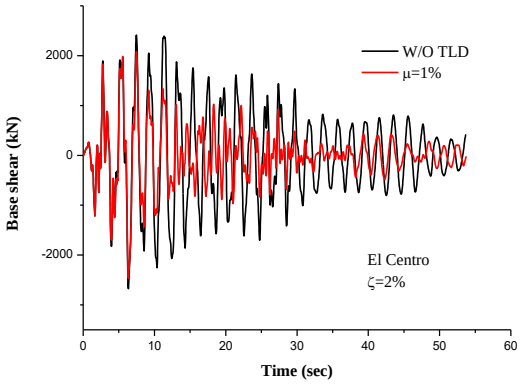


(d) Parkfield earthquake

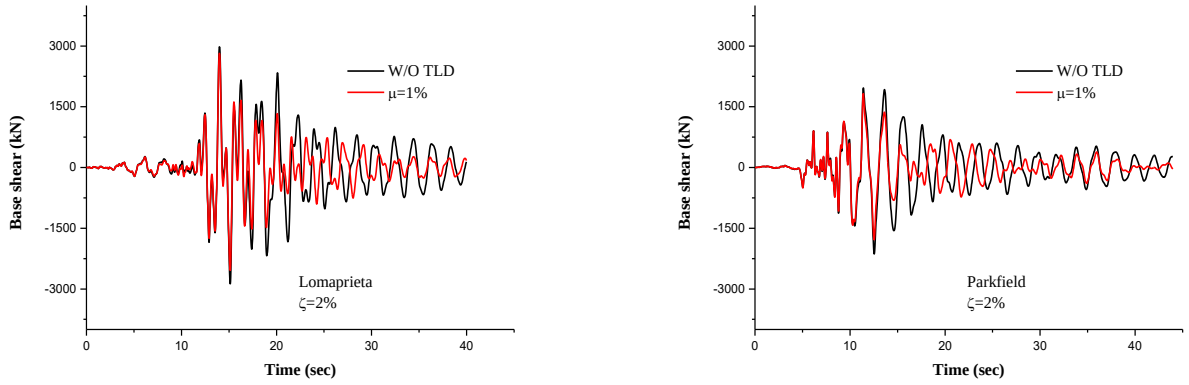
Figure 6: Variation of base shear of structures with time for 1% damping ratio of structures considering different real earthquake accelerograms, (a)-(d).



(a) Chamoli earthquake



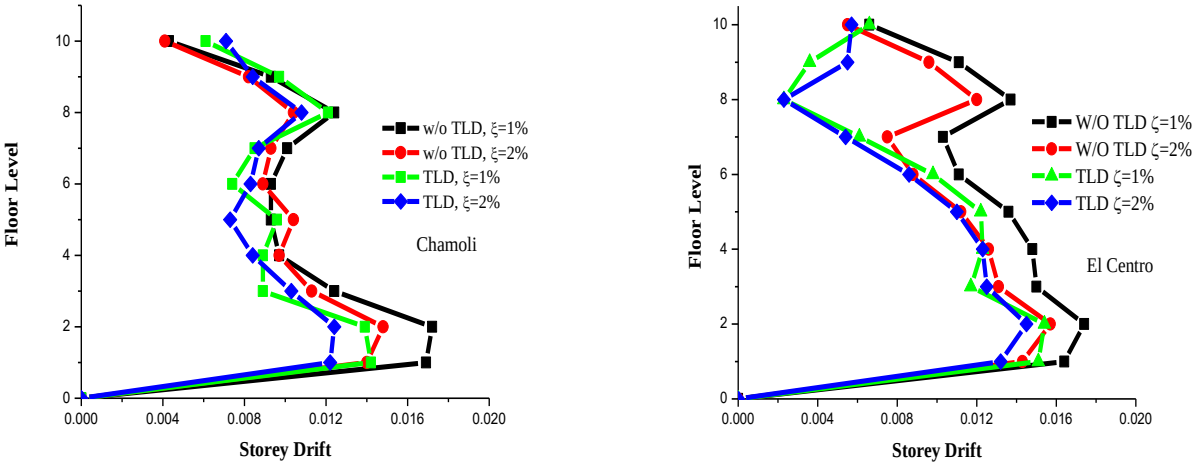
(b) El Centro earthquake



(c) Lomaprieta earthquake (d) Parkfield earthquake

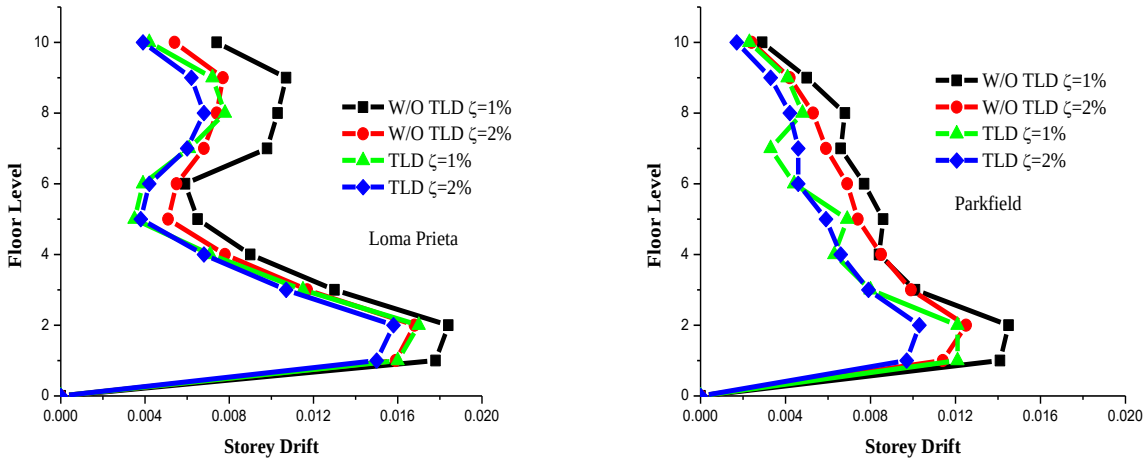
Figure 7: Variation of base shear of structures with time for 1% mass ratio and 2% damping ratio of structures considering different real earthquake accelerograms, (a)-(d).

The variation of storey drift at each storey of building with time considering time history data of Chamoli, El Centro, Lomaprieta and Parkfield earthquake for TLD system and 1-2% damping ratio of structure are shown in Figure 8and 9. It is observed that, TLD is more effective to reduce the storey drift at the 2nd floor of the structure when the structure having a low damping ratio.



(a) (b)

Figure 8: Floor level vs. storey drift for(a) Chamoliand (b) El Centro earthquake



(a) (b)

Figure 92: Floor level vs. storey drift. (a) Lomaprieta and (b) Parkfieldearthquake

5. CONCLUSIONS

For the sake of comparison, a ten storied building is analysed without damper and with TLD systems and time history analysis is performed with some real earthquake data. A maximum reduction of Base shears of 17% is observed when structural damping (ζ) is 1%, and 15% when structural damping is 2%.The percent reduction of top storey displacement of structures($\zeta = 1\%$), like, 10.63%, 26.83%, 22.42% and 24.13% for Chamoli, EL Centro, Lomaprieta and Parkfield earthquake using TLD system.So performance of TLD is more effectively when it is installed at the structure having low damping ratio.

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