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Application of Tuned Mass Damper for Vibration Control of Multistoried Building under Seismic Excitation

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Abstract

Current trends in construction industry demands taller and lighter structures, which are also more flexible and having quite low damping value. Now-a-days several techniques are available to minimize the vibration of the structure, out of the several techniques available for vibration control; concept of using TMD is a newer one. This study was made to study the effectiveness of using TMD for controlling vibration of structure. The numerical stimulations are performed to study the structure with and without TMD. A twelve storied building with rectangular shape is considered for analysis. Analysis is done by FE software SAP2000 by using direct integration approach. TMDs with percentage masses 2%, 3%, 4%, 5% are considered. Three different recorded time histories of past EQ are used for the analysis. Namely 1940 EL-Centro EQ, Northridge EQ, and Taft EQ. comparison is done between the buildings with TMD and without TMD. From the study it was found that, TMD can be effectively used for vibration control of structure. TMD was more effective when damping ratio is less. Gradually increase in the mass ratio of the TMD result in gradually decrement in the displacement response of the structure.

Keywords- Tall Building, TMD, Soft-Storey, Vibrations, Earthquake

I. INTRODUCTION

Fast urbanization has led to construction of a large number of multistoried buildings. Seismic safety of these building is very important. Efforts have led to develop the techniques like base isolation, active control and passive control devices. Base isolation technique is shown to be quite effective and it requires insertion of isolation device at the foundation level, which may require constant maintenance. Active control techniques turn out to be quite costly for buildings, as they need continuous power supply. In developing countries like India, such control devices can become popular only if they are easy to construct. Their design method is compatible with present practices and shall not require costly maintenance. With the aim of developing such a simple control device, some studies have been undertaken in last couple of years. In these studies a simple type of Tuned Mass Damper (TMD) has been proposed. A tuned mass damper (TMD) is a passive energy dissipation device, consists of a mass, spring, and a damper, connected to the structure in order to reduce the dynamic vibrations induced by wind or earthquake loads. The soft storey will be made up of concrete and its columns, beams, and slab sizes will be smaller than columns, beams, and slab sizes other stories of the building. The height, member sizes of soft storey will be devised based on the principle of TMD i.e. the natural frequency of TMD (soft storey) should have same natural frequency as that of main building. [1]

The number of tall buildings being built is increasing day by day. Today we cannot have a count of number of low-rise or medium rise and high rise buildings existing in the world. Mostly these structures are having low natural damping. So increasing damping capacity of a structural system, or considering the need for other mechanical means to increase the damping capacity of a building, has become increasingly common in the new generation of tall and super tall buildings. But, it should be made a routine design practice to design the damping capacity into a structural system while designing the structural system.

The control of structural vibrations produced by earthquake or wind can be done by various means such as modifying rigidities, masses, damping, or shape, and by providing passive or active counter forces. To date, some methods of structural control have been used successfully and newly proposed methods offer the possibility of extending applications and improving efficiency. The selection of a particular type of vibration control device is governed by a number of factors which include efficiency, compactness and weight, capital cost, operating cost, maintenance requirements and safety. TMD is attached to a structure in order to reduce the dynamic response of the structure. The frequency of the damper is tuned to a particular structural frequency so that when that frequency is excited, the damper will resonate out of phase with the structural motion. The mass is usually attached to the building via a spring-dashpot system and energy is dissipated by the dashpot as relative motion develops between the mass and the structures. [2]

A. Passive Energy Dissipation

All vibrating structures dissipate energy due to internal stressing, rubbing, cracking, plastic deformations, and so on; the larger the energy dissipation capacity the smaller the amplitudes of vibration. Some structures have very low damping of the order of 1% of critical damping and consequently experience large amplitudes of vibration even for moderately strong earthquakes. Methods of increasing the energy dissipation capacity are very effective in reducing the amplitudes of vibration. Many different methods of increasing damping have been utilized and many others have been proposed. [2]

Passive energy dissipation systems utilize a number of materials and devices for enhancing damping, stiffness and strength, and can be used both for natural hazard mitigation and for rehabilitation of aging or damaged structures. In recent years, efforts have been undertaken to develop the concept of energy dissipation or supplemental damping into a workable technology and a number of these devices have been installed in structures throughout the world. In general, they are characterized by the capability to enhance energy dissipation in the structural systems in which they are installed. This may be achieved either by conversion of kinetic energy to heat, or by transferring of energy among vibrating modes. The first method includes devices that operate on principles such as frictional sliding, yielding of metals, and phase transformation in metals, deformation of viscoelastic solids or fluids, and fluid orificing. The later method includes supplemental oscillators, which act as dynamic vibration absorbers. [3]

B. Tuned Mass Damper

The concept of the tuned mass damper (TMD) dates back to the 1940 [4]. It consists of a secondary mass with properly tuned spring and damping elements, providing a frequency-dependent hysteresis that increases damping in the primary structure. The success of such a system in reducing wind-excited structural vibrations is now well established. Recently, numerical and experimental studies have been carried out on the effectiveness of TMDs in reducing seismic response of structures. [5]

II. METHODOLOGY

Analysis of G+12 storied building with and without installation of TMD. Analysis and design is done by the SAP 2000 software. A soft storey at the top of building reduces top building deflection. Tuned mass damper in the form of soft storey of Steel is found to be effective in reducing seismic forces. Among 2%, 3%, 4%, 5% mass ratios of TMDs are used to reduce the seismic response of building. Three earthquake records are used to response reduction in the time historey analysis using EL- Centro, Northridge and Taft.

A. Building Description

The model of building is G+12 storey RCC structure considered for the analysis. The building has bay width of 5m in X and Y direction with 3.5m storey height. Base floor height is 4.5m. Tuned mass damper is installed at the top of building. Linear time historey analysis is carried out in SAP2000 software using three earthquake records such as EL Centro earthquake, Northridge earthquake and Taft earthquake.

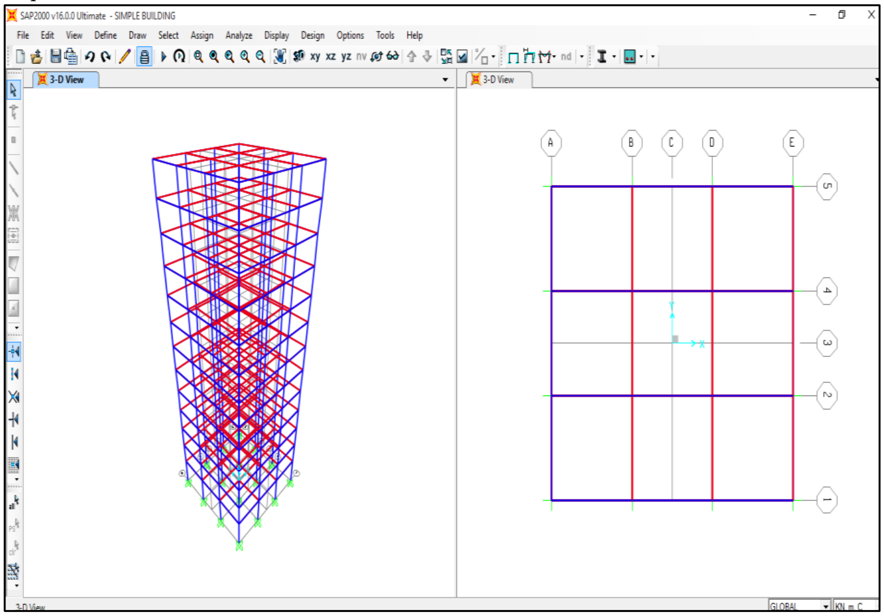

Fig. 1: Plan of G+12 Building

B. Numerical Data for Building

Table 1: Numerical Data for Analysis

Sr.No.	Content	Description
1.	Number of storey	G+12
2.	Floor height	3.5m
3.	Base floor height	4.5m
4.	Wall thickness	230mm
5.	Imposed load	$3KN/m^2$
6.	Size of column	450mm×450mm
7.	Size of beam	450mm×300mm
8.	Depth of slab	100mm
9.	Types of soil	Medium soil
10	Grade of Concrete/Steel	M30/Fe415
10.	Seismic zone	V
11.	Zone factor	0.36
12.	Response of spectra	As per IS1893(Part 1):2002 for 5% damping
13.	L.L. On top	$1.5 KN/m^2$

III. RESULT AND DISCUSSION

A. Optimum Parameter of TMD

Sizes of TMD are reduces to normal building sizes which are given in table 2.

Table 2: Different Mass Ratios of TMD With main Building

Sr. No.	Description	Mass Ratio of TMD with main building in %			
		2%	3%	4%	5%
1	Column Section	ISB113.5×113.5×5.4			
2	Beam Section	ISWB600			
3	Slab Thickness (M 30) (m)	0.13	0.22	0.3	0.38
4	Storey height (m)	7	6	5.5	5.1

B. Effect of Mass Ratio

In this discussion comparison is carried out for each model with different mass ratios. It is observed here that, natural periods increases as the mass ratio increases and the percentage variation of natural period increases with increase in number of storey. The percentage variations for different mass ratio with different number of storey are tabulated in the table 3.

Table 3: Comparison of natural periods for 12 storey building

Sr. No.	No. of Mode	Time period Normal Building (sec)	Time period of Building with TMD (sec)			
			2%	3%	4%	5%
1.	1.	3.83	4.29	4.44	4.49	4.58
2.	2.	3.83	4.29	4.44	4.49	4.58
3.	3.	3.39	3.72	3.82	3.89	3.96
4.	4.	1.26	3.43	3.35	3.29	3.23
5.	5.	1.26	3.43	3.35	3.29	3.23

6.	*6.*	*1.12*	*3*	*2.94*	*2.89*	*2.84*
7.	*7.*	*0.72*	*1.24*	*1.25*	*1.24*	*1.24*
8.	*8.*	*0.72*	*1.24*	*1.25*	*1.24*	*1.24*
9.	*9.*	*0.65*	*1.11*	*1.11*	*1.11*	*1.11*
10.	*10.*	*0.5*	*0.72*	*0.72*	*0.72*	*0.72*
11.	*11.*	*0.5*	*0.72*	*0.72*	*0.72*	*0.72*
12.	*12.*	*0.45*	*0.65*	*0.65*	*0.65*	*0.65*

C. Time Histories of Random Ground Acceleration

A total of three random ground acceleration cases are considered for the analysis. The first is the compatible time historey is the 1940 El Centro Earthquake record. Second is the compatible time historey is the 1994 Northridge Earthquake record. Third is the compatible time historey is the 1952 Taft Earthquake record

The response of symmetrical building with tuned mass damper for various ground motion is investigated in terms of displacement and acceleration.

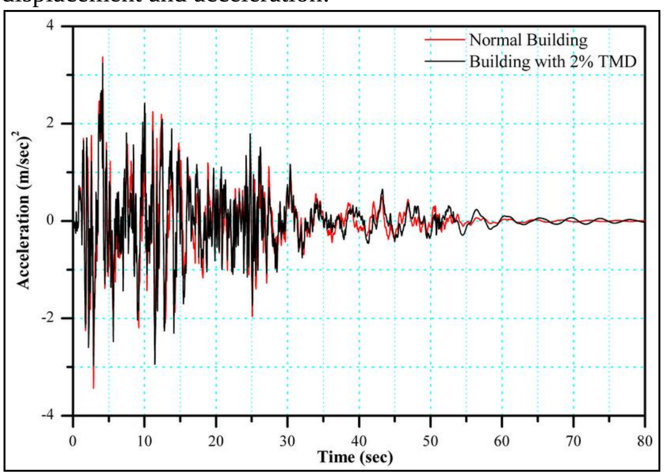

Fig. 2(a): 2% Mass Ratio

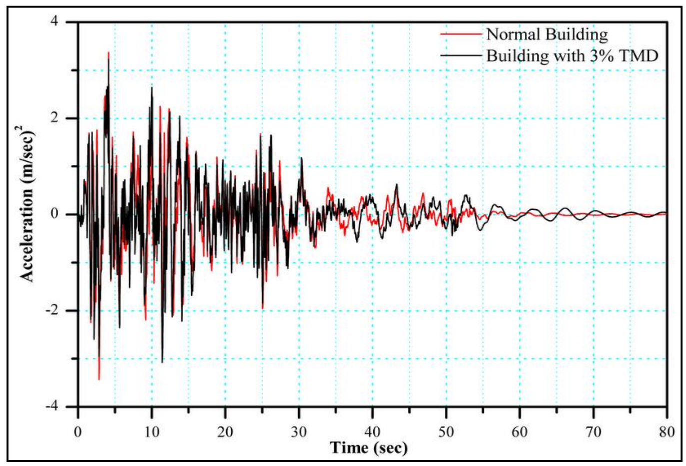

Fig. 2(b): 3% Mass Ratio

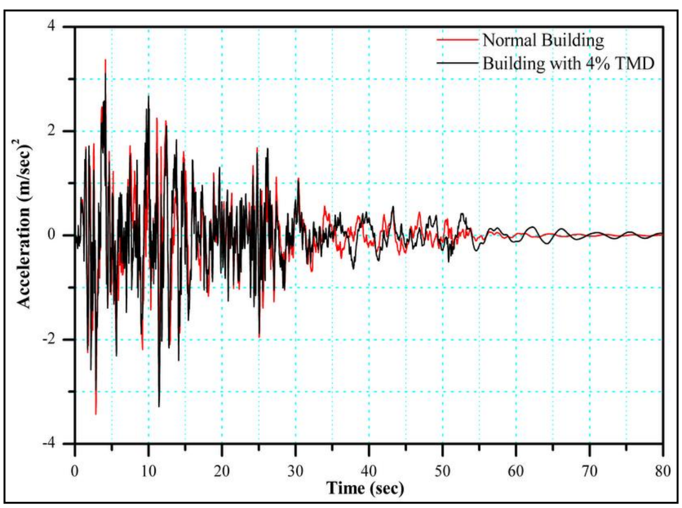

Fig. 2(c): 4% Mass Ratio

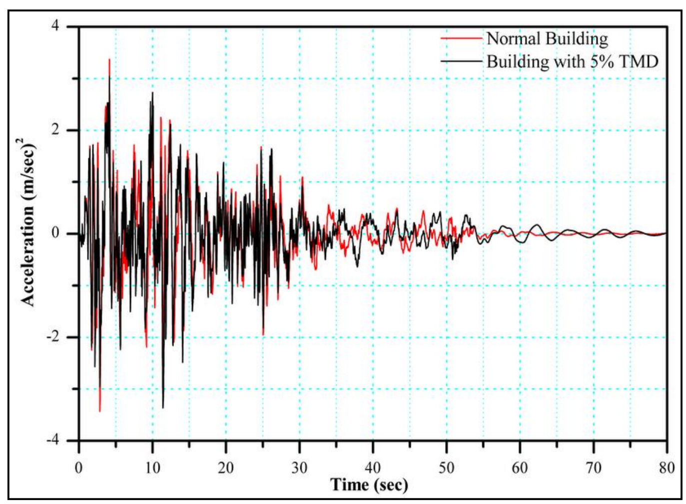

Fig. 2(d): 5% Mass Ratio

Fig. 2: Acceleration vs Time response graph of the structure for 1940 EL-Centro Earthquake

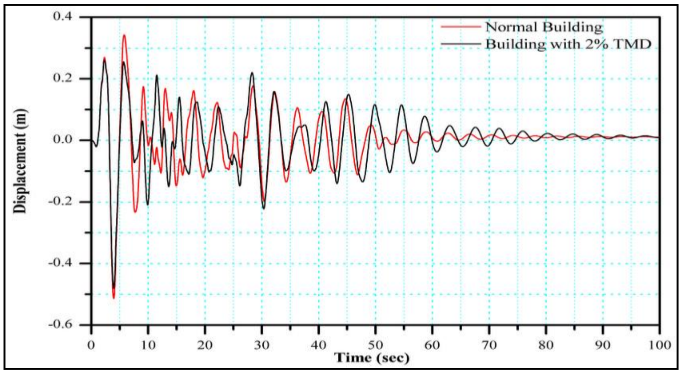

Fig. 3(a): 2% Mass Ratio

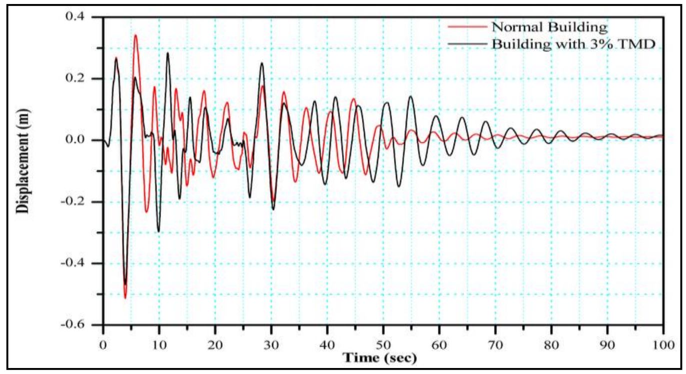

Fig. 3(b): 3% Mass Ratio

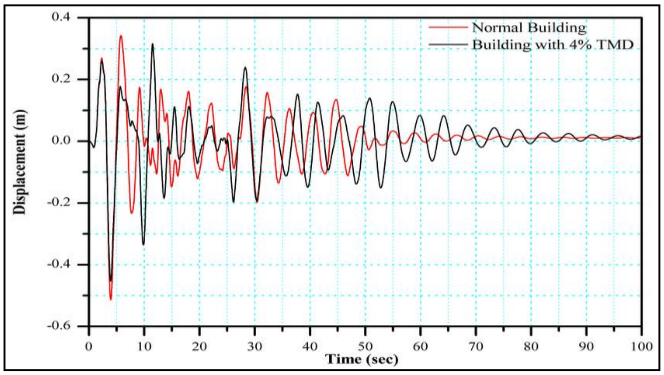

Fig. 3(c): 4% Mass Ratio

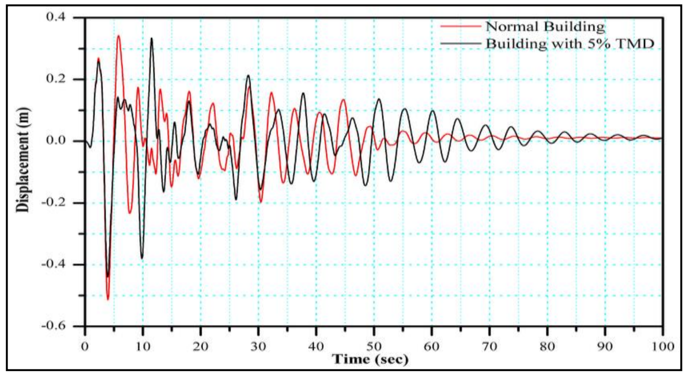

Fig. 3(d): 5% Mass Ratio

Fig. 3: Displacement vs Time response graph of the structure for 1940 EL-Centro Earthquake

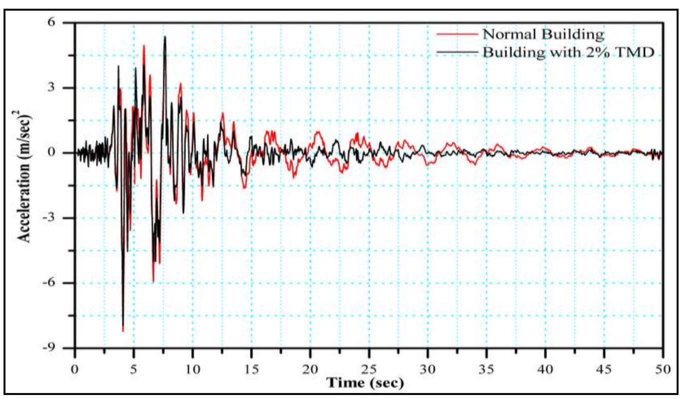

Fig. 4(a): 2% Mass Ratio

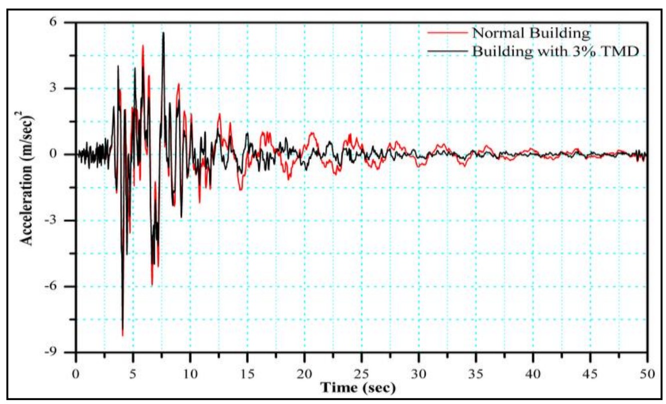

Fig. 4(b): 3% Mass Ratio

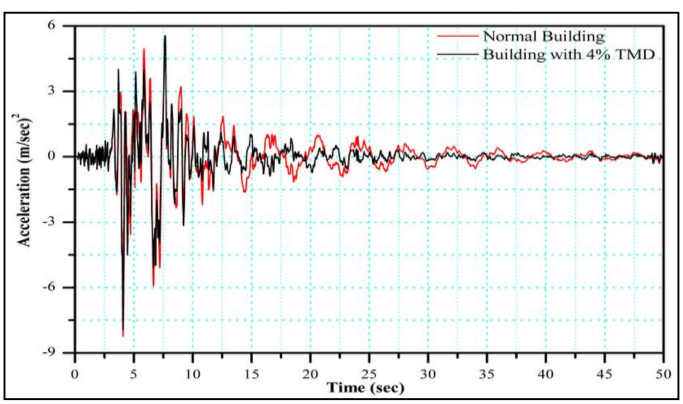

Fig. 4(c): 4% Mass Ratio

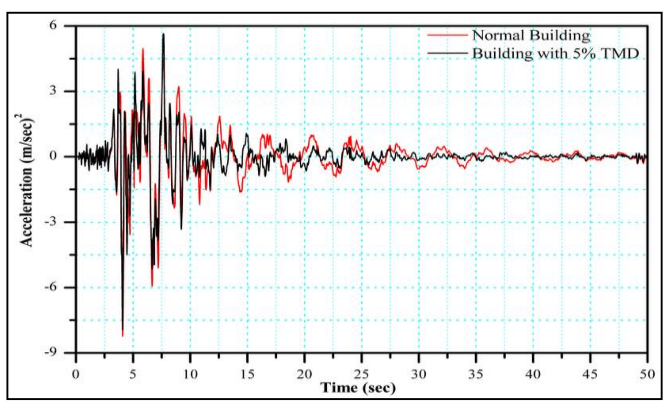

Fig. 4(d): 5% Mass Ratio

Fig. 4: Acceleration vs Time response graph of the structure for Northridge Earthquake

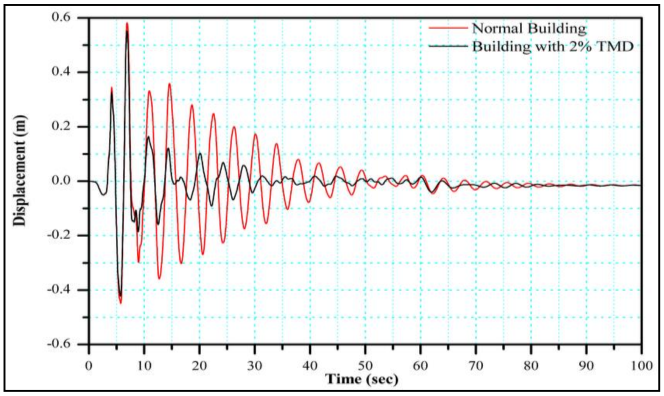

Fig. 5(a): 2% Mass Ratio

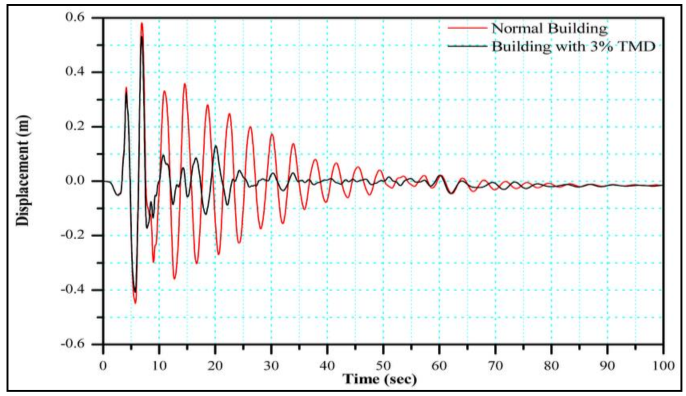

Fig. 5(b): 3% Mass Ratio

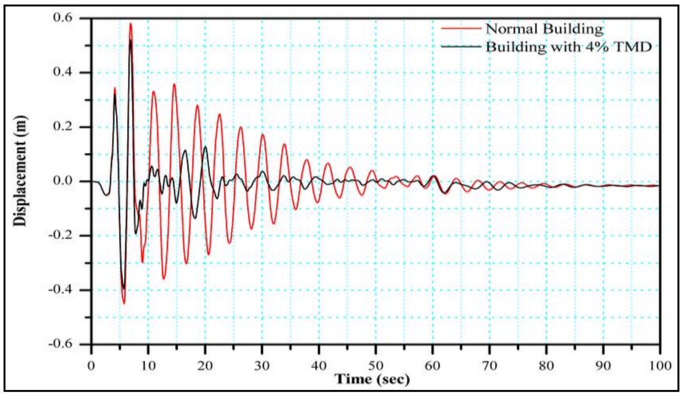

Fig. 5(c): 4% Mass Ratio

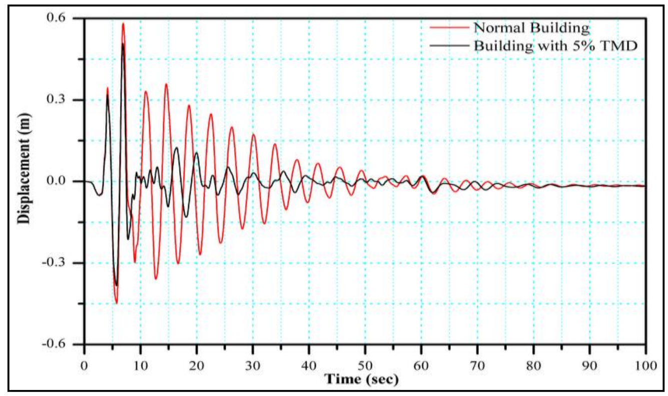

Fig. 5(d): 5% Mass Ratio

Fig. 5: Displacement vs Time response graph of the structure for Northridge Earthquake

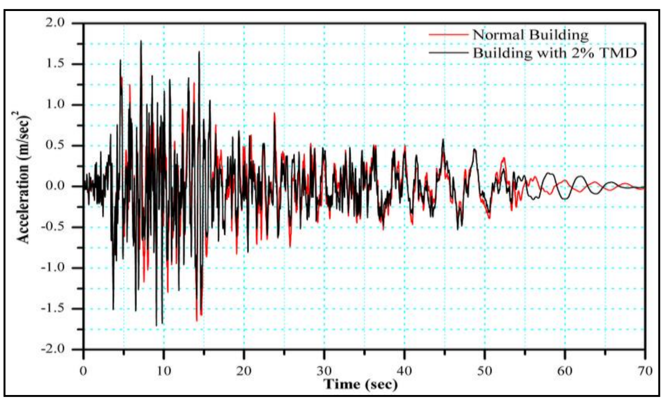

Fig. 6(a): 2% Mass Ratio

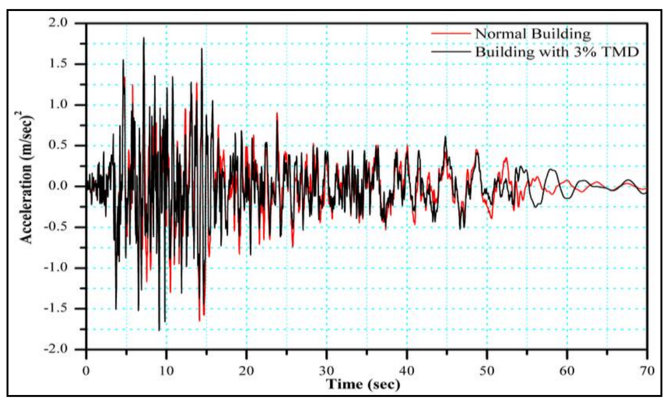

Fig. 6(b): 3% Mass Ratio

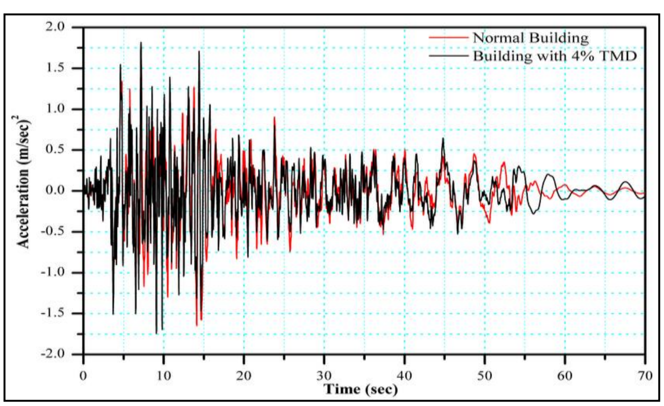

Fig. 6(c): 4% Mass Ratio

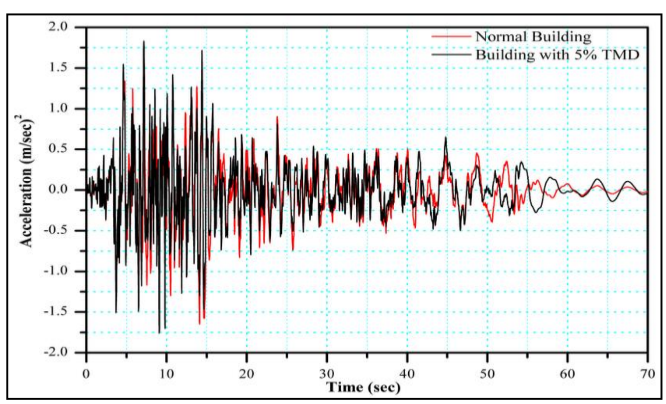

Fig. 6(d): 5% Mass Ratio

Fig. 6: Acceleration vs Time response graph of the structure for Taft Earthquake

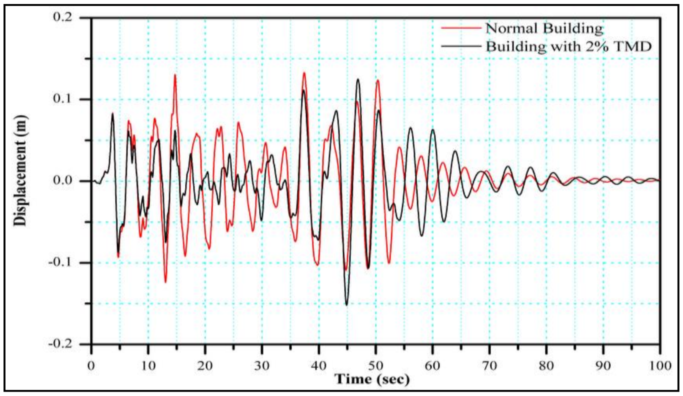

Fig. 7(a): 2% Mass Ratio

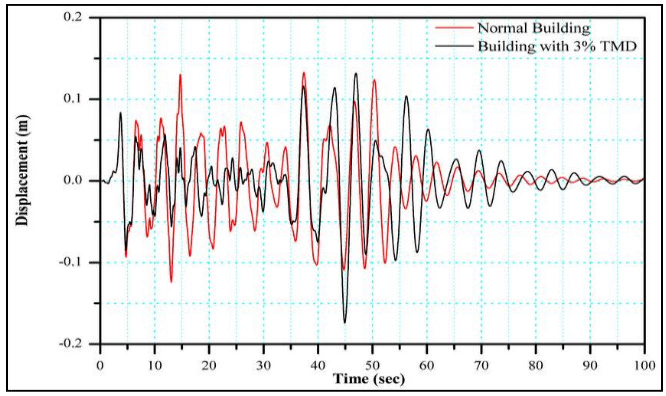

Fig. 7(b): 3% Mass Ratio

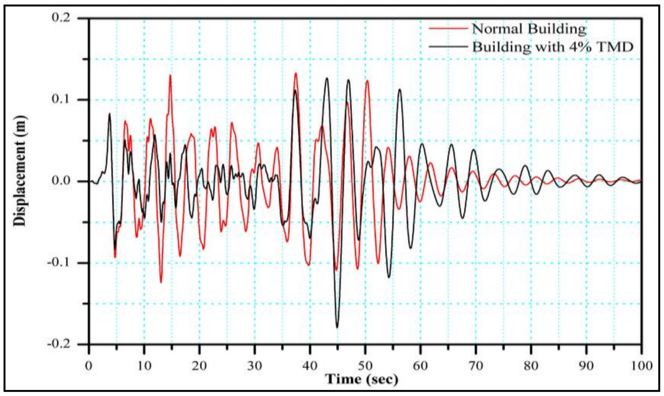

Fig. 7(c): 4% Mass Ratio

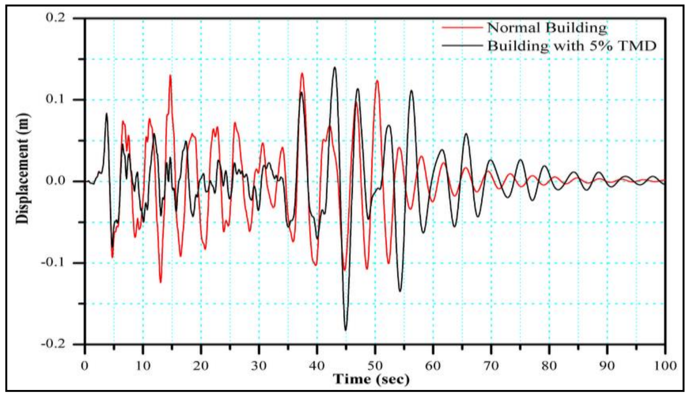

Fig. 7(d): 5% Mass Ratio

Fig. 7: Displacement vs Time response graph of the structure for Taft Earthquake

D. Results in Three Earthquake Record

The results obtained for El- Centro earthquake record is as shown in figure 3 for 12 storey building. Introduction of TMD in RC frame increases the time period of RC frame without TMD. It has been found that TMD of mass ratio 5% configuration there was nearly about 61% response reduction take place. Depending on the mass of the TMD 20% to 60% reduction in displacement takes place.

Table 4: Result of El-Centro EQ

Sr. No.	*% of mass for TMD*	*% of Reduction in displacement*
1	*2*	*26.82*
2	*3*	*40.97*
3	*4*	*50.29*
4	*5*	*61.01*

The results obtained for Northridge earthquake record is as shown in figure 5 for 12 storey building. Introduction of TMD in RC frame increases the time period of RC frame without TMD. Depending on the mass of the TMD 6% to 15% reduction in displacement takes place. And detuning effect not takes place.

Table 5: Result in Northridge EQ

Sr. No.	% of mass for TMD	% of Reduction in displacement
1	2	6.36
2	3	9.44
3	4	12.23
4	5	14.96

The results obtained for Taft earthquake record is as shown in figure 7 for 12 storey building. Introduction of TMD in RC frame increases the time period of RC frame without TMD. Depending on the mass of the TMD 40% to 67% reduction in displacement takes place. 5% mass of TMD is more effective than other three masses.

Table 6: Result in Taft EQ

Sr. No.	*% of mass for TMD*	*% of Reduction in displacement*
1	*2*	*39.93*
2	*3*	*55.87*
3	*4*	*61.01*
4	*5*	*67.29*

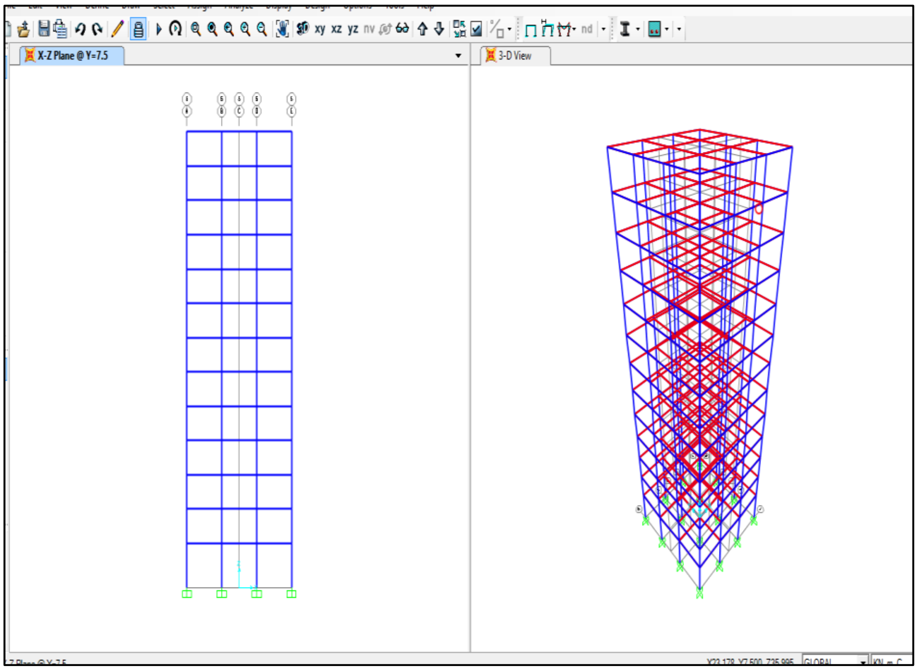

Fig. 8: Building without TMD

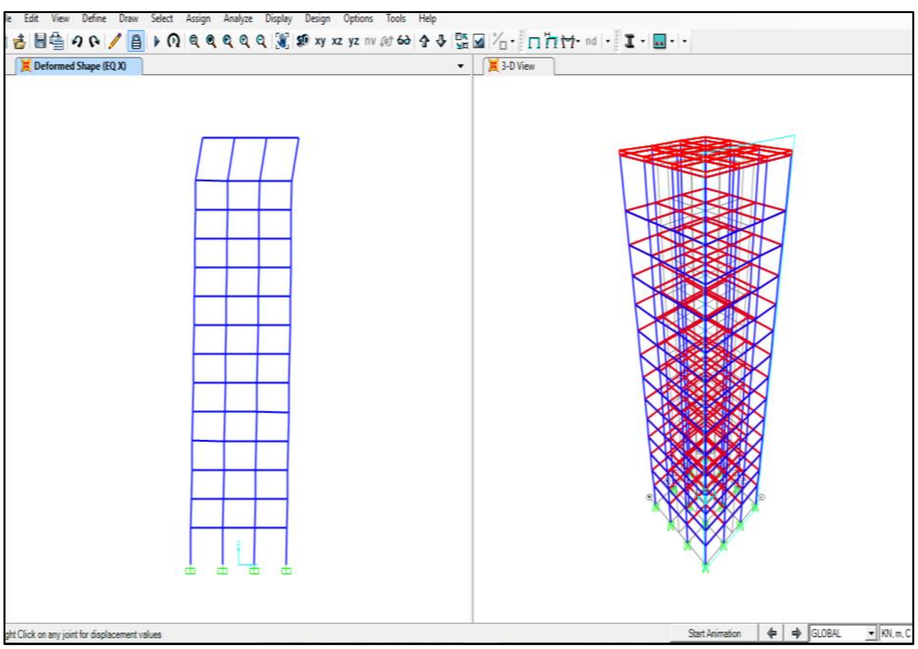

Fig. 9: Building with TMD

IV. CONCLUSIONS

1) It has been found that the TMD can be successfully used to control vibration of the structure.
2) Simple TMD with optimum frequency ratio, provided in the form of soft storey at building top is found to be effective in reducing seismic response of building.
3) Applying the three earthquake loadings first is the corresponding to compatible time historey in the EL-Centro earthquake. a soft storey at the top of building reduces top building deflection about 20%-61%
4) Second is the corresponding to compatible time historey in the Northridge earthquake a soft storey at the top of building reduces top building deflection about 6%-15%
5) Third is the corresponding to compatible time historey in the Taft earthquake a soft storey at the top of building reduces top building deflection about 38%-67%
6) Among 2% to 5% TMDs 5% TMD is found better than 2%, 3%, 4% TMDs in reducing displacement.

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