SINAI International Scientific Journal (SISJ)

Volume 1, Issue 2, October 2024

Seismic Analysis of R.C Multi-Story Buildings Controlled by Tuned Mass Dampers

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Citation:

Abouhallawa, A. S.," Seismic Analysis of R.C Multi-Story Buildings Controlled by Tuned Mass Dampers", SINAI International Scientific Journal (SISJ), volume 1,Issue 2, pp. 95-104, 2024

Received: 29 April 2024

Accepted: 1 July 2024

ABSTRACT

Tuned-Mass dampers, if well-tuned to a particular natural frequency, are an attractive solution in reducing excessive vibrations of buildings subjected to strong and unpredictable earthquakes. Two important parameters greatly affect the building seismic response are the input energy to the building and the dissipated energy of the structure. The optimum design is one that minimizes the difference between these two energies. This research aims to evaluate the effects of Tuned- Mass dampers on energy dissipation. Tuned mass dampers dissipate a great amount of energy. Without their existence, this energy would damage the building or disturb the occupants. Analysis of a ten-story reinforced concrete building with and without TMD using ETABS software is carried out. The tuned mass damper is placed on top of the building. The dynamic response of structures due to earthquakes is greatly reduced when tuned mass dampers are used. Results indicate the increase in mass of the TMD enhances the R.C building response to seismic vibrations.

KEYWORDS: Seismic analysis -Tuned mass dampers - Time history - YERMO Earthquake.

1. INTRODUCTION

The earthquakes are the most serious threat for structures. They not only disturb normal life pattern but also cause huge losses is lives and properties and interrupt the process of development. Earthquake study is far less sufficient to get most effective solutions. Earthquake disaster prevention and reduction strategy is big concern in the present days. Further research in this field is going on in the last decades to get more effective design and to control building vibrations [1-4]. Many techniques exist to minimize the vibration induced by earthquake shock. For example, Tuned Mass Dampers TMD can be used to minimize the seismic effects on buildings [5-8].

The use of TMD dampers is an effective and economical tool to minimize the amplification of building vibration and dissipate its input energy. Tuned Mass Dampers make the structure receive less seismic energy to dissipate. [9-12]. Most of the research work has proven that TMD are effective tools to improve seismic response of high-rise RC building. Dampers are structural devices that can be easily replaced later in case of damage after an earthquake. Due to the random and unexpected nature of seismic forces, it is necessary to enhance structural analysis procedures to analyze structures when subjected to earthquakes [13-17]. The ratio between the mass of damper and mass of buildings is the mass ratio. When the mass ratio increases, the TMD become more effective. This ratio is in the range of 1-10%. Using optimum value of damping, it is possible to control the vibration of the original structure over a wider frequency range [18-21]. The effectiveness of TMD is decreased significantly by the off-tuning or the off-optimum damping [22-26].

The TMD is a passive device made up of a mass, spring, and damper. It is mounted to a structure to control its dynamic response. The TMD is constructed with the natural frequency adjusted to that of the main structure [27-31]. If a specific frequency of the primary structure is excited, the TMD resonates out of phase with the structural motion, reducing its sensitivity to seismic loads [32]. The TMDs are often mounted at the summit of buildings and are tuned to the structure's first mode frequency. The frequencies of both the TMD and the structure should be approximately the same, so that when the seismic force pushes the building, the TMD generates an opposing force, keeping its horizontal displacement as zero or near zero. If the frequency of TMD differs from the primary structure, the building motion will remain uncomfortable for residents. A TMD's effectiveness is primarily dependent on its mass, frequency, and damping ratios [33-34].

ETABS software is used in this study. ETABS is a structural program that uses finite elements to analyze and design of civil structures. It has shown to be the most comprehensive, productive, and general-purpose structural program available today. Also, ETABS is the most straightforward solution for high-rise building structural analysis and design.

2. OBJECTIVES

Analysis of symmetrical moment resistance 10-story three-dimensional RC frame using ETABS software is carried out. Natural periods of the first 12 modes are calculated with and without TMD (2.5%, 5%, and 10% of primary structure mass). Seismic responses (Story displacement, Story acceleration, and Base shear) of the building with and without TMD are found. Nonlinear dynamic analysis using YERMO time history earthquake functions are carried out. The results obtained from analysis are compared.

3. ETAB Modeling

3.1 Building Model

The analysis was conducted on a ten-story reinforced concrete building with a total height of thirty meters and six bays in both the x and y directions. The bay width in both x and y directions is 4m, and the height of each story is 3 meters. Assumed data for analysis is given below in Table 1.

Table 1: Assumed Analysis Data.

1	**Slab thickness**	**15 cm**
2	Columns and beams	30 x 60 cm
4	Covering load	150 kg/m^2
5	Mass Source	Dead load only
6	Seismic load	Time history- YERMO Earthquake

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3.2 Tuned-Mass Dampers

The TMD of three different mass ratios 10%, 5%, and 2.5% will be mounted to the top of the model to observe the seismic behavior of the structure. The dampers modeled in ETABS is given I Fig.1. Table 2 provides the structural parameters of the tuned mass dampers.

Table 2: Details of Tuned Mass Dampers TMD Data.

	10% TMD	5% TMD	2.5% TMD
Mass of the damper	50000 kg	25000 kg	12500 kg
Stiffness in x- y and z direction	295000kg/m	590000 kg/m	1180000 kg/m
Effective damping in the x-direction	250000 kg/sec/m	200000 kg/sec/m	15000 kg/sec/m
Effective damping in the y-direction	200000kg/sec/m	150000 kg/sec/m	100000 kg/sec/m
Effective damping in the z-direction	150000 kg/sec/m	100000kg/sec/m	50000 kg/sec/m

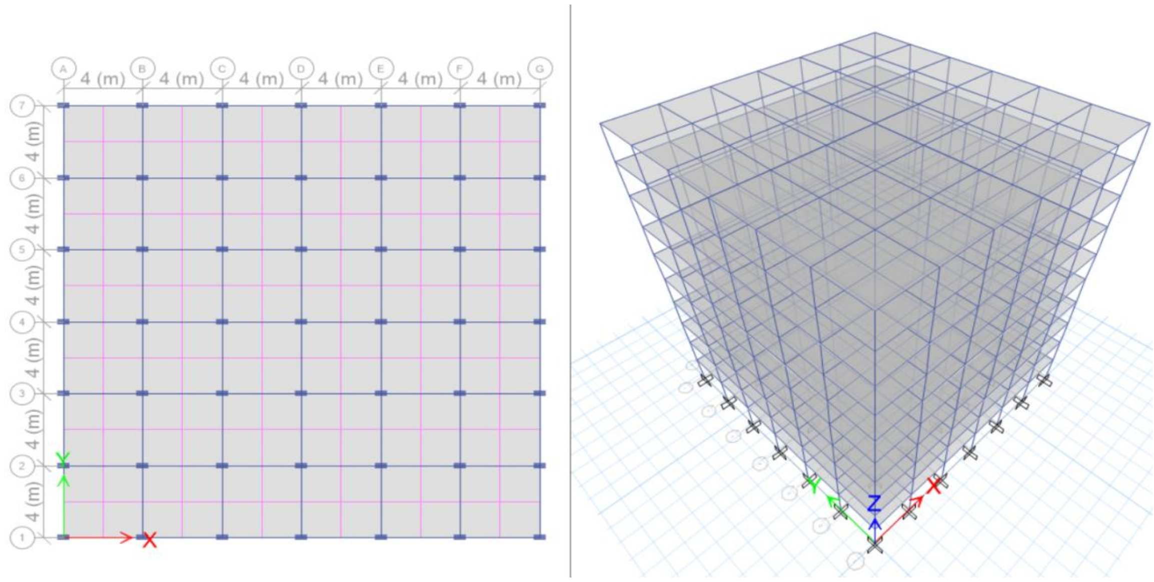

Fig. 1: Proposed ETAB Model.

4. Methodology

In this study, a three-dimensional 10-story building is modeled in ETABS software with and without the TMD. A non-linear time history dynamic analysis of the building has been performed using YERMO Earthquake functions. Displacement, Acceleration, base shear and frequency of the building with and without TMD are calculated and compared.

5. Results and Discussion

5.1. Displacement

To maintain the structure safe and comfortable, the displacement induced by an earthquake should be reduced by using TMD. The horizontal displacement of the diaphragm of each story in Y-direction with and without TMD has detailed in Table 3 and Fig.2.

Table 3: Displacement at Diaphragm of each Floor with and without TMD.

Diaphragm	Displacement in (mm)			
	Without TMD	2.5 % Mass ratio TMD	5% Mass ratio TMD	10% Mass ratio TMD
1	7.202	4.812	3.729	2.474
2	14.899	10.404	8.044	5.908
3	21.678	15.678	12.135	8.839
4	27.6	18.822	15.768	11.552
5	32.926	20.415	18.985	14.357
6	37.377	24.471	21.77	16.981
7	41.089	27.906	24.032	19.206
8	44.093	33.36	25.846	20.964
9	46.289	35.805	27.416	22.184
10	47.616	37.16	28.577	23.037

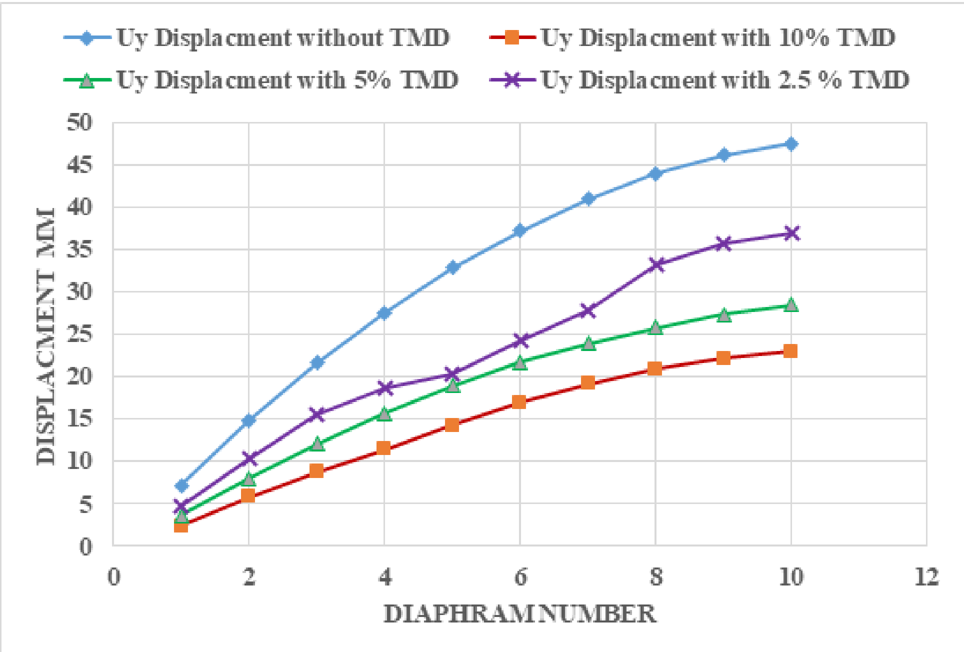

Fig. 2: Diaphragms versus Displacements

Fig.2 shows the relationship between displacement of each diaphragm mass center of each story of the structure with and without TMD. It is obvious that the maximum displacement at the 10th diaphragm of structure without TMD is 48 mm. After providing TMD with different mass ratios 2.5%, 5%, and 10%, displacement at 10th diaphragm of structure is reduced to 36 m, 28 mm, 22 mm respectively.

5.2. Acceleration

Acceleration is the change in velocity at the structure's diaphragms is caused by a seismic force operating on it. Acceleration at the diaphragm center of each floor with and without TMD is shown in Table 4 and Fig. 3. It is shown that maximum acceleration at tenth diaphragm of the structure in first mode without TMD is 1.75 m/sec^2. After providing TMD with different mass ratios 2.5%,5%,10%, the maximum acceleration at diaphragm 10 of the building in first mode is reduced to 0.8m/sec^2 , 0.62m/ sec^2, 0.61 m/sec^2.

Table 4: Acceleration at Diaphragm Center of each Floor with and without TMD.

Diaphragm	Acceleration in (m/sec^2)			
	Without TMD	2.5 % Mass ratio TMD	5% Mass ratio TMD	10% Mass ratio TMD
1	0.58681	0.3714	0.3707	0.3733
2	0.9667	0.4937	0.4881	0.4987
3	1.20415	0.5342	0.5112	0.5241
4	1.27526	0.585	0.5153	0.4973
5	1.24713	0.61614	0.5732	0.5947
6	1.08082	0.5793	0.5048	0.5034
7	0.86917	0.5174	0.3874	0.3378
8	1.1225	0.5477	0.5019	0.4705
9	1.35554	0.6477	0.5698	0.5121
10	1.76399	0.7882	0.7026	0.6526

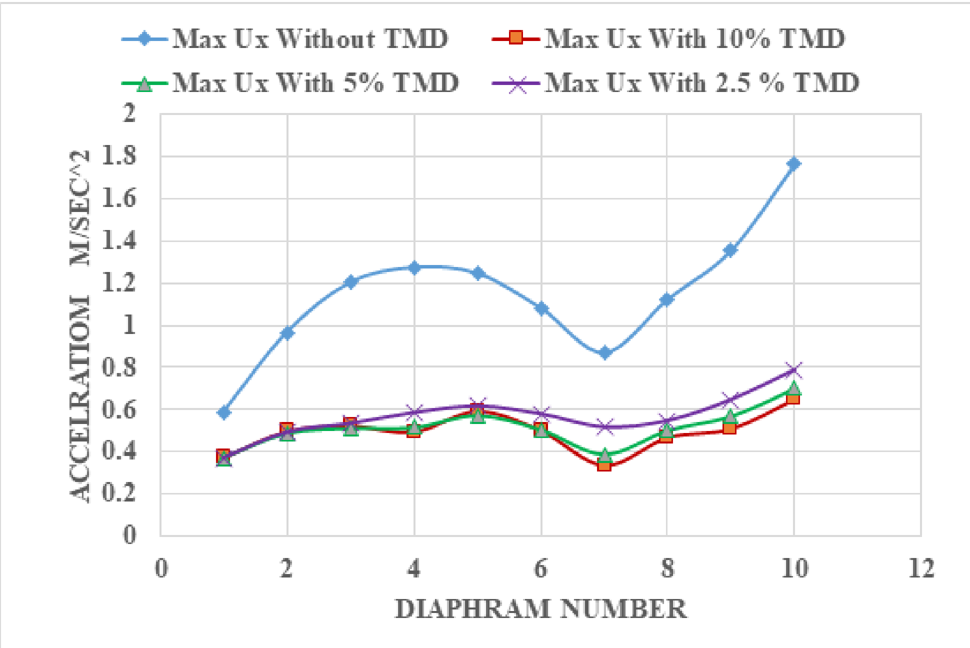

Fig. 3: Diaphragm number versus Acceleration.

5.3. Natural Periods

The time in which a complete cycle of oscillation occurred is called the period. The structural period is one of the most critical aspects in the structure's seismic analysis. The modal analysis is carried out for the structure. The periods of different models with 0%, 2.5%, 5%, and 10% mass ratios are calculated and compared. As the TMD mass ratio increased the periods increased especially in the first two modes. This means that the structure become more flexible with TMD. Periods of the first twelve mode of structure with and without TMD have tabulated in Table 5 and graphed in Fig.4.

5.4 Base shear

Base shear is an important factor in failure of structures subjected to strong earthquake. Reducing it using TMD is important. The base shear is the shear value obtained from the sum of lateral forces at the levels above the base of the structure due to earthquake. Base shear with and without TMD are shown in Table 6 and Fig.5.

Table 5: Natural Periods of the First Twelve Modes with and without TMD.

Mode Number	Periods in (second)			
	Without TMD	2.5 % Mass ratio TMD	5% Mass ratio TMD	10% Mass ratio TMD
1	1.293	1.478	1.579	1.743
2	0.914	1.36	1.421	1.532
3	0.872	1.182	1.153	1.123
4	0.431	0.917	0.918	0.922
5	0.302	0.914	0.914	0.914
6	0.286	0.856	0.844	0.826
7	0.256	0.429	0.428	0.427
8	0.184	0.302	0.302	0.302
9	0.178	0.286	0.286	0.285
10	0.166	0.256	0.256	0.255
11	0.144	0.184	0.184	0.184
12	0.125	0.178	0.178	0.178

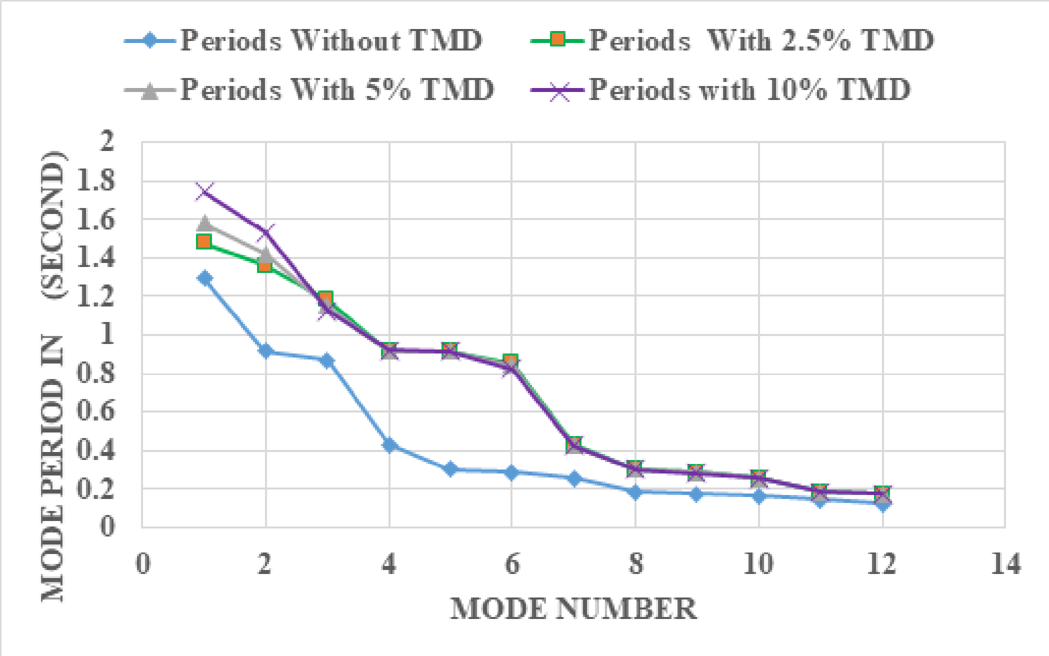

Fig. 4: Mode number versus Natural Periods.

Table 6: Base Shear with and without TMD.

% Mass	Without TMD	2.5% TMD	5% TMD	10% TMD
Base shear (Ton)	440.9903	281.054	**218.241**	150.040

From Fig. 6, it is observed that the values decrease due to providing TMD with different mass ratios 2.5%,5%, 10%. The base shear reduced up to 36% for 2.5% TMD, to 51% for 5% TMD, and to 66 % for 10%-TMD damper

6. CONCLUSION

ETABS software has made it much simpler to evaluate the effect of TMD dampers. Seismic response of RC building can be improved by using TMD dampers which dissipate the input energy throughout the earthquake. Consequently, the reduction in induced seismic forces leads to a notable reduction in construction cost. Furthermore, it reduces the repair cost after an earthquake strike, and makes the occupants of high stories feel more comfortable. The response of the building with TMD is entirely different without dampers. In this study, nonlinear dynamic time history analysis has been performed for a 10-story concrete building. This analysis makes it possible to comprehend how the tuned mass dampers reduce the seismic effect on a building. As the TMD mass ratio increased, the response is more enhanced.

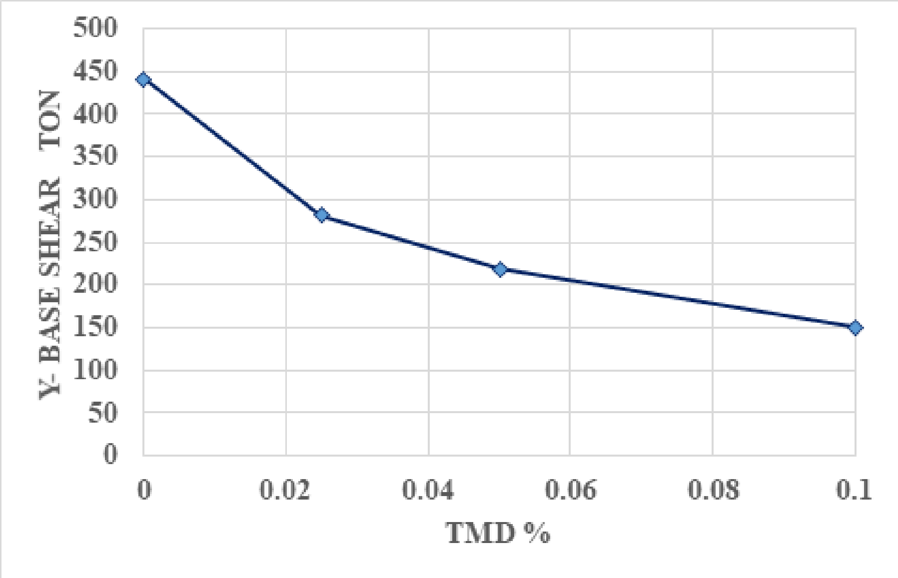

Fig. 5: Mode number versus Natural Periods.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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