NOVATEUR PUBLICATIONS
JournalNX- A Multidisciplinary Peer Reviewed Journal
ISSN No: 2581 - 4230
VOLUME 7, ISSUE 12, Dec. -2021

THE EFFECT OF TMD ON THE PERIODS AND MODE SHAPES OF THE REINFORCED CONCRETE BUILDING BY FINITE ELEMENT ANALYSIS

Sertac Tuhta
Civil Engineering Department,
Ondokuz Mayis University, Samsun, Turkey
stuhta@omu.edu.tr

Furkan Gunday
Civil Engineering Department
Ondokuz Mayis University, Samsun, Turkey
furkan.gunday@omu.edu.tr

Emrecan Koroglu
Civil Engineering Department
Ondokuz Mayis University, Samsun, Turkey

ABSTRACT:

Earthquake engineers have taken many precautions in their building designs to protect and minimize destructive effects. In this way, many new design and reinforcement methods have been developed against seismic loads. The use of a tuned mass damper (TMD) is one of the developed methods. One of the most important negative aspects of the use of TMD is the increase in the structural period. Therefore, in this study, the effects of TMD on periods and mode shapes in simeterically reinforced concrete building model were investigated. For this, two models with and without TMD were created by the finite element method and modal parameters were compared. As a result of the data obtained, it has been observed that the building model makes more balanced displacements, as can be understood from the mode shapes, without increasing the period of the building to a dangerous level. It is known that TMD reduces the seismic effect by acting in the opposite direction to the seismic effect on the structure. Tuned mass damper can be used in structures, provided that it does not increase the structure period too much.

Keywords: Tuned mass damper; mode shape; period; RC building; FEA.

I. INTRODUCTION:

A tuned mass damper (TMD), also known as a harmonic absorber or seismic damper, is a device mounted in structures to reduce mechanical vibrations, consisting of a mass mounted on one or more damped springs. Its oscillation frequency is tuned to be similar to the resonant frequency of the object it is mounted to, and reduces the object's maximum amplitude while weighing very much less than it.

TMDs can prevent discomfort, damage, or outright structural failure. They are frequently used in power transmission, automobiles and buildings. Tuned mass dampers stabilize against violent motion caused by harmonic vibration. They use a comparatively lightweight component to reduce the vibration of a system so that its worst-case vibrations are less intense. A tuned mass damper (TMD) is a device mounted [1] in structures to reduce mechanical vibrations, consisting of a mass mounted on one or more damped springs. Its oscillation frequency is tuned to be similar to the resonant frequency of the object it is mounted to, and reduces the object's maximum amplitude while weighing very much less than it. The mass damping of a structure is generated by a spring, acting on a mass, and thereby mechanically damping the vibrating movement. This generates a variation in the stress or weight (also known as stiffness or damping force) in the structure, based on the spring frequency. The applied force is thus less than that of the mass of the structure. This allows a structure to respond to a nonlinear frequency change and hence to cope with an accident, vibration, or to operate with a different frequency, which may be different from that of the environment. Different kinds of mass dampers are used in different situations. A three-point adjustable mass damper has a single mass fixed to a threaded rod which can move in a number of planes around a central axis. Usually, it has a lever to adjust the central force. If the lever is pulled up the mass will be pushed to the top of the module, and if it is pulled down the mass will be pushed to the bottom of the module. If two levers are fixed to each other at their respective ends, the mass is allowed to move in both directions. The amplitude of the motion can be reduced by closing the two ends of the damper. In many marine applications, such as tugs, the mechanism can include dampers with segments, allowing the damper to absorb energy by dissipating energy in the water. In cars, the dampers are in between the wheel and the wheel arch, and are made to be as soft as possible so as to create minimum camber on the wheel, and avoid rolling or pitching motions. Most cars have multiple dampers mounted in different locations on the vehicle to control different frequencies of vibrations. Some aircraft use tuning forks, which are tuned by balancing them with a weighted weight.

The dampers used in a building or vehicle are usually made of a type of plastic called polyurethane or elastomer, with a high temperature die-cast resin. The mass acting on the spring may be a spring steel coil, some kind of nylon mat, or some kind of polymer. In some applications, the mass can be of a massless sort (see fixed damping below) or have a mass. The mass may be a pure mass, a "floating mass" (a solid mass suspended in a fluid), or a composite of the two. The mass tends to keep the damping force constant up to a point, after which it starts to transfer energy to the spring. The spring is usually either a steel coil or a nylon mat. The coil gives the damping force a direct mechanical connection to the suspension, which eliminates moving parts, and the mat absorbs some of the shock.

The spring-mass damping mechanism is a unique and important contribution to the damping of the structure. It allows the building or vehicle to make use of more mechanical parts per unit of mass and provides a benefit in terms of comfort and safety. It can be used to reduce speed and weight in cars and trucks, yet keep the ride and handling smooth and controlled. It may be used to control vibration in building structures, to increase comfort and safety, or to operate at a different frequency (e.g., have a different speed than the surrounding environment). Controlling and smoothing of the external vibrations is usually handled by manipulating the shape of the mass. Controlling the internal vibrations is usually handled by creating different spring rates. The different spring rates are used to reduce the frequency of the vibration and increase the duration, or because some vibration is undesirable and needed to be suppressed. The combination of the different spring rates is referred to as the damping rate. The frequency of the internal vibrations is determined by the amplitude of the vibration, and the damping rate may be adjusted to reduce or increase the frequency.

Controlling and smoothing of vibrations is more critical in buildings than in cars. Cars are usually running faster, around a few mph; it is possible to run the car too fast in a building by overloading the springs of the suspension. In addition, internal damping is needed in buildings. Many kinds of active dampers (usually air suspension systems) can also be controlled to avoid excessive jiggling. The weight-bearing mass can be either the spring's material as a whole, the metal coil contained in the coil, or the weight of the coil inside the coil (discrete mass). In cars, the material in the spring has the most mass because it can be directly connected to the drive train. In buildings, a mass may be made of a number of individual pieces; a common method is to stack compressed air cylinders. It is very important that the mass of the coil be in contact with the spring, so that the coils are spring loaded. In addition, the mass must not move, so any mass in the coil must be compressed and/or otherwise supported against pressure. A coil is normally compressed in the vanes of an air compressor. Because mass can also be made up of any number of pieces, and because the coil can be any length, the spring may be a rod, a strand of wire, a flat bar of rubber, or any number of other materials. Usually, coils are constructed from nickel-silver, tungsten, or stainless-steel wire. Sometimes springs are made from organic materials, such as gelatin, jellies, or polyurethanes. Coils are supported in some way, usually by nylon mats or strips of rubber. Spring masses are stressed by the forces and strains acting on them, and these forces and strains will depend on the geometry and material properties of the spring. Typical stresses include compressive stresses, centripetal stresses, radial forces, and longitudinal forces. The natural frequency of the spring is usually around 0.001Hz. Compressive forces are usually 1-2MPa, centripetal stresses can be 2-8 MPa, radial forces can be 10-100 MPa, and longitudinal forces can be 50-100 MPa. The spring properties are used to specify the spring rate. Generally, spring forces are increased during full load, which is when the force per unit length is 100-200 times the force at rest. Also, because a spring's stiffness does not depend on the geometry of the spring, spring rates can be changed quickly by changing the force acting on the mass. Stress rates may be controlled by adjusting the mass and the mass diameter. Some springs are flexible, some rigid; some dampers have spring rates with wide variation from a minimum to a maximum, and some have very narrow ranges of spring rates. Some springs are made with tensile coils and are spring-loaded; this allows the coils to be tensioned and compressed to their maximum tension, so that the springs may be much stiffer than the coils, with springs having a much smaller mass. When different materials are used for the different parts of a spring, some practical differences will be seen. For example, in spring-loaded dampers, the coil, however stiff, will be connected to a steel support rod. This rod is then connected to a plastic retaining clamp. Because the spring mass is lighter than the steel support rod, the spring mass will exert a force that deforms the plastic clamp, usually down by a large amount. Since the spring mass is not being strained, it will usually be able to overcome the spring load. However, during cyclic loading, the compression force on the clamp may become very large. As a result, even though the mass may seem to resist compression, in reality, it is in fact being crushed by the clamp. In this case, spring rate may be controlled by changing the clamp. Spring units, like damper units, may also be made from more than one material. Coils are usually bent into curves, and in some cases, into ellipses. This shape is chosen to provide greater spring load resistance. However, all parts of a spring can be designed to take any shape, provided that there are sufficient forces acting on it to provide the spring rate. Another consideration is that most metals are not a good choice for spring coils. For example, a steel spring coil, due to the large amount of stress, tends to bend to the point of failure and will actually snap. Furthermore, the small stresses that can be applied by spring coils can be a problem, especially when they are bent into curves. Spring coils are usually made from metals, such as copper, steel, or beryllium copper, which are a good choice for spring coils. A spring can be made from three primary materials: Damper units are usually made from many different materials. These include steel, aluminum, ceramic, plastic, and rubber. Most spring units, especially spring-loaded damper units, are made of steel, which is the most common material. Plastic can be a very good choice for a damper, because plastic can be easily molded to a desired shape, and because the plastic has relatively little compressive stress, which means that when a load is applied, there will be little to no plastic deformation. However, plastic coils are usually quite stiff, which means that the damper unit will need to be supported by springs. Some springs are made from many different materials. This allows the damper unit to be flexible, which is often beneficial, since it can be made to be large enough to support the desired spring load.

There have been various scientific studies of researchers [2], [3], [4], [5], [6], [7], [8], [9], [10], [11], [12] on tuned mass damper (TMD) since the 1980s, which guided this study. In addition, there are current studies of the authors [13], [14], [15], [16], [17], [18], [19], [20], [21], [22] using the finite element method to determine modal parameters (frequency, period, damping, mode shape etc.).

II. DESCRIPTION OF RC BUILDING:

The building consists of five floors. Columns and beams are 30x60 cm in size, slab thickness is 15 cm. The concrete class of the building was chosen as C30/37. The steel rebar class of the building was chosen as S420. Building features are also given in Table 1.

TABLE I. BUILDING FEATURES

Number of floors	5
Total building height	15 m
Floor height	3 m
Number of openings in X direction	2
Number of openings in Y direction	2
Spacing of apertures in X direction	5 m
Spacing of apertures in Y direction	5 m

The building finite element model was created using the SAP 2000 package program. The building was modeled symmetrically in order to see the TMD effects better. The finite element model of the building is given in figure 1.

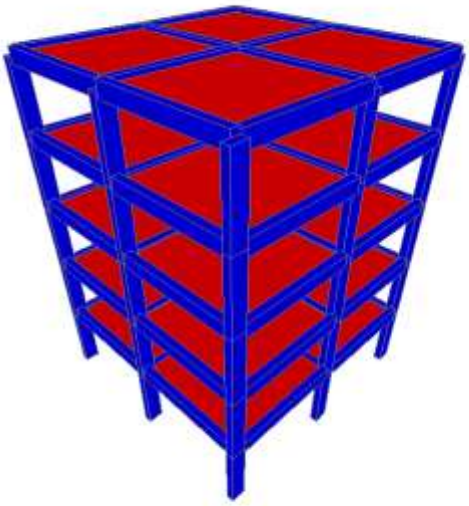

Fig. 1. Finite element model of the building

The building was first analyzed in its current state using SAP2000 with the finite element method, then TMD was added to the top floor and the same analysis was repeated and the results were compared.

III. DESCRIPTION OF TMD:

Suspended vertically at the midpoint of the 5th floor, with a mass of 50 kN, fixed in the x-y-z axes, it has a stiffness of 1000000, 1000, 1000 kN/m and a damping of 50, 50, 0.5 kNs/m, respectively. Location of TMD in building is given in figure 2.

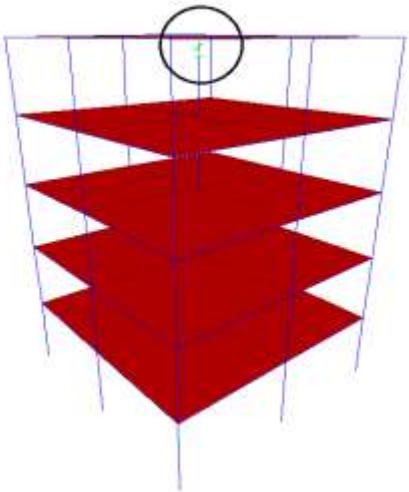

Fig. 2. Location of TMD

IV. ANALYSIS AND RESULTS:

The building was first analyzed in its current state using SAP2000 with the finite element method, then TMD was added to the top floor and the same analysis was repeated and the results were compared.

A. Results of the Building without TMD

The building was analyzed without adding tuned mass damper (TMD) by finite element method. The first 5 modes were taken into account in the analysis. Obtained results are presented in figures 3,4,5,6,7 as periods and mode shapes.

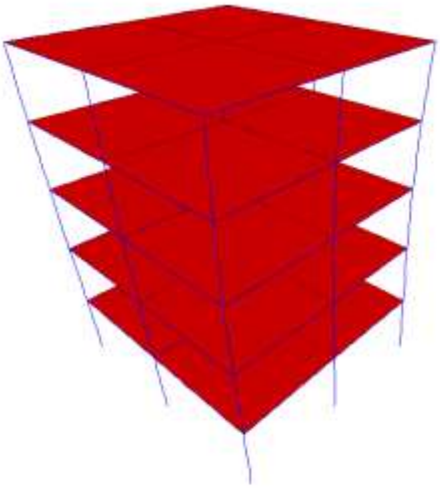

Fig. 3. Period of the given building according to Mode 1= 0.6347 s

It is seen that the building whose representation is given according to Mode 1 is shifted in the x direction.

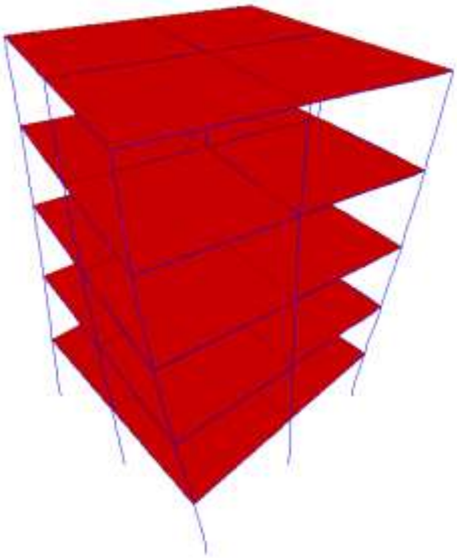

Fig. 4. Period of the given building according to Mode 2= 0.4557 s

It has been observed that the building shown according to Mode 2 has torsion.

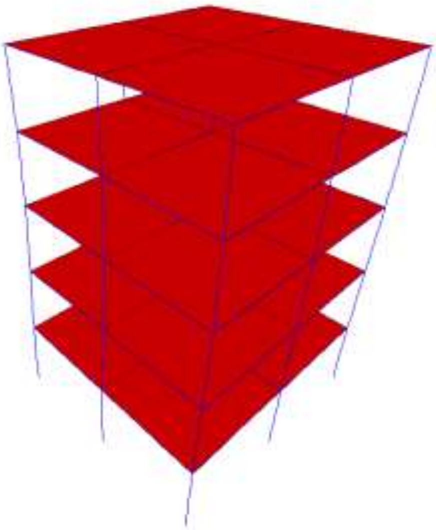

Fig. 5. Period of the given building according to Mode 3= 0.4376 s

It is seen that the building whose representation is given according to Mode 3 is shifted in the y direction.

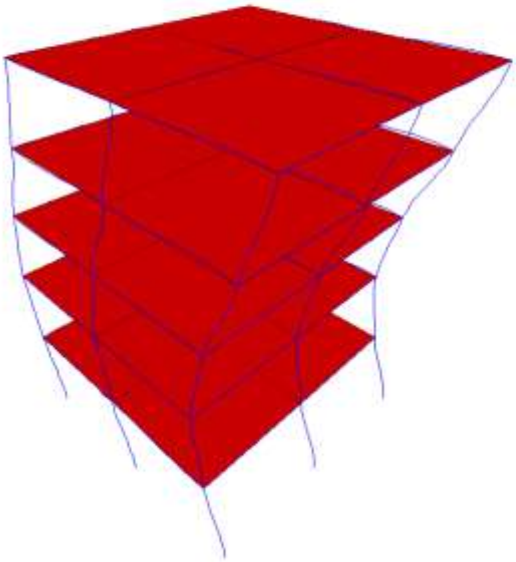

Fig. 6. Period of the given building according to Mode 4= 0.2113 s

It is seen that the building whose representation is given according to Mode 4 is shifted in the y direction. It also draws attention to some torsion.

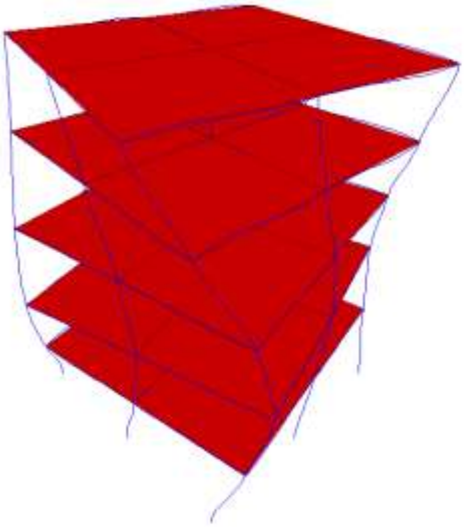

Fig. 7. Period of the given building according to Mode 5= 0.1397 s

It has been observed that the building shown according to Mode 5 has torsion.

B. Result of the Building with TMD:

The building was analyzed with adding tuned mass damper (TMD) by finite element method. The first 5 modes were taken into account in the analysis. Obtained results are presented in figures 8,9,10,11,12 as periods and mode shapes.

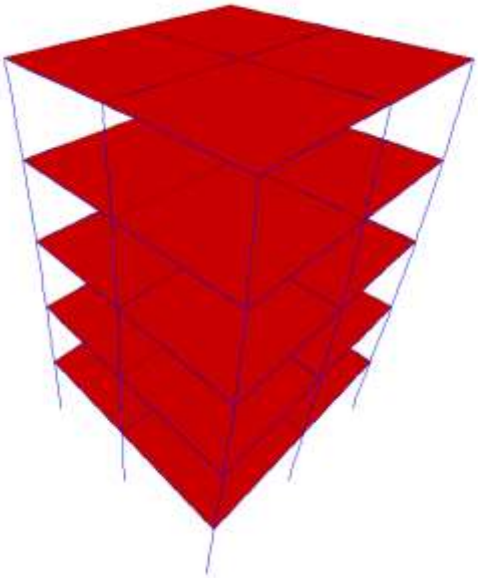

Fig. 8. Period of the given building according to Mode 1= 0.6576 s

It is seen that the building whose representation is given according to Mode 1 is shifted in the y direction.

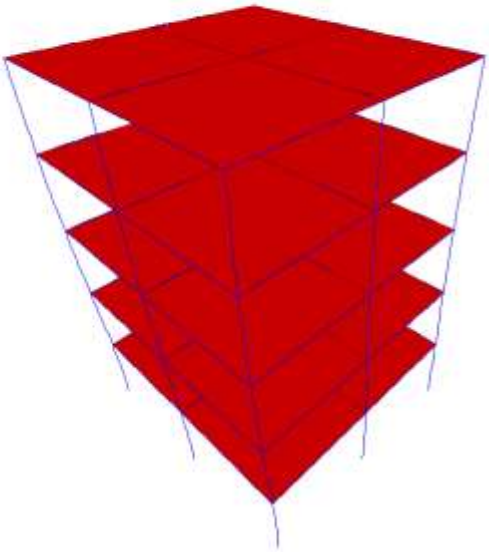

Fig. 9. Period of the given building according to Mode 2= 0.4609 s

It is seen that the building whose representation is given according to Mode 2 is shifted in the x direction.

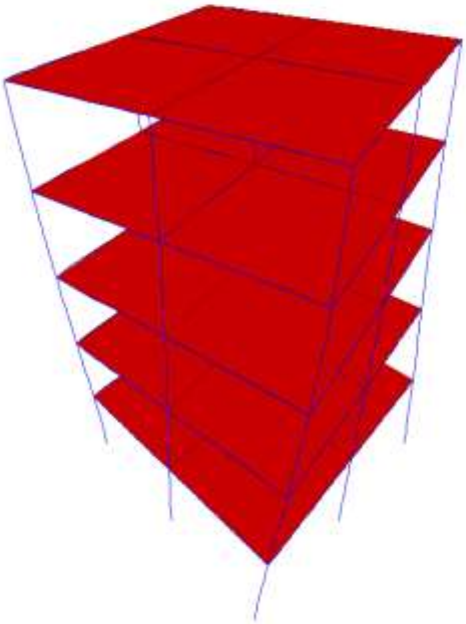

Fig. 10. Period of the given building according to Mode 3= 0.4557 s

Fig. 11.

It has been observed that the building shown according to Mode 3 has torsion.

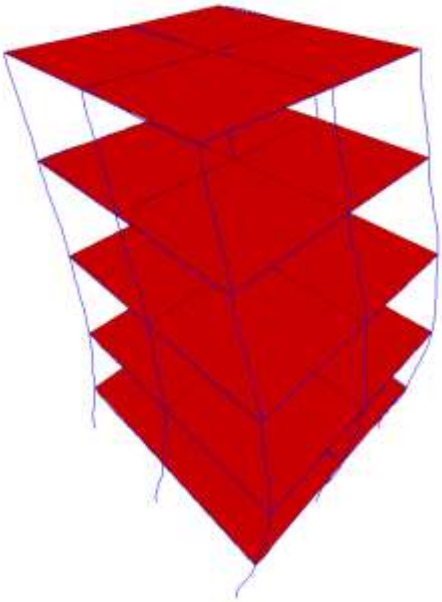

Fig. 12. Period of the given building according to Mode 4= 0.2213 s

It is seen that the building whose representation is given according to Mode 4 is shifted in the y direction. It also draws attention to some torsion.

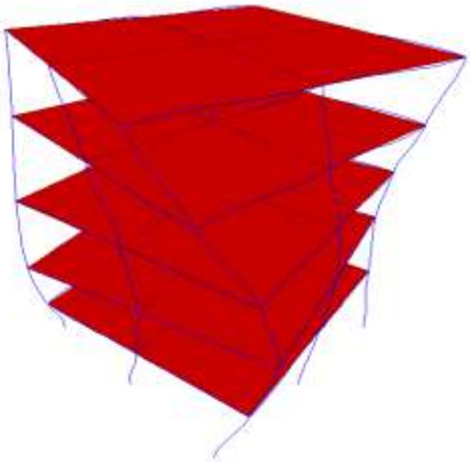

Fig. 13. Period of the given building according to Mode 5= 0.1397 s

It has been observed that the building shown according to Mode 5 has torsion.

C. Comparison of Analysis Results:

The comparison of period of the model with TMD and without TMD model is given in Table 2.

TABLE II. COMPARISON PERIOD OF WITHOUT TMD MODEL AND WITH TMD MODEL

Mode	1	2	3	4	5
Without TMD Period (s)	0.6347	0.4557	0.4376	0.2113	0.1397
With TMD Period (s)	0.6576	0.4609	0.4557	0.2213	0.1475
Difference (s)	0.0229	0.0052	0.0181	0.0100	0.0078
Difference (%)	3.60	1.14	4.13	4.73	5.58

The comparison of mode shapes of the model with TMD and without TMD model is given in Table 3.

TABLE III. COMPARISON MODE SHAPES OF WITHOUT TMD MODEL AND WITH TMD MODEL

Mode	1	2	3	4	5
Without TMD Mode Shapes	Shifted	Torsion	Shifted	Shifted	Torsion
With TMD Mode Shapes	Shifted	Shifted	Torsion	Shifted	Torsion

V. CONCLUSIONS:

The percentage changes in the parameters of the building are listed below.

In the mode 1, the period difference between non-TMD and TMD status was obtained as 0.0229 s. The effect of TMD reinforcing as a percentage was determined as 3.60%.

In the mode 2, the period difference between non-TMD and TMD status was obtained as 0.0052 s. The effect of TMD reinforcing as a percentage was determined as 1.14%. In addition, when the mode shape is examined, it is seen that it transforms from torsion to shift.

In the mode 3, the period difference between non-TMD and TMD status was obtained as 0.0181 s. The effect of TMD reinforcing as a percentage was determined as 4.13%. In addition, when the mode shape is examined, it is seen that it transforms from shift to torsion.

In the mode 4, the period difference between non-TMD and TMD status was obtained as 0.0100 s. The effect of TMD reinforcing as a percentage was determined as 4.73%.

In the mode 5, the period difference between non-TMD and TMD status was obtained as 0.0078 s. The effect of TMD reinforcing as a percentage was determined as 5.58 %.

As a result of the study, it has been observed that the building model makes more balanced displacements, as can be understood from the mode shapes, without increasing the period of the building to a dangerous level. TMD reduced the seismic effect by acting in the opposite direction to the seismic effect on the structure. It can be used in TMD structures, provided that it does not increase the structure period too much.

REFERENCES:

1) Yao Zhang, Jingrui Zhang, Guang Zhai. "Vibration Isolation Platform with Multiple Tuned Mass Dampers for Reaction Wheel on Satellites", Mathematical Problems in Engineering, 2013.
2) Nam Hoang, Yozo Fujino, Pennung Warnitchai, “Optimal tuned mass damper for seismic applications and practical design formulas”, Engineering Structures, Volume 30, Issue 3, pp. 707-715, 2008.
3) Chen Y., Jin X., Liu H., Li F., Luo M. “Large scale wind turbine TMD optimization based on Blade-Nacelle-Tower-Foundation Coupled Model”, Ocean Engineering, Volume 239, 2021.
4) Steen Krenk, “Frequency Analysis of the Tuned Mass Damper”, J. Appl. Mech. Nov 2005, 72(6): 936-942
5) Amir M. Kaynia, Daniele Veneziano, and John M. Biggs, “Seismic Effectiveness of Tuned Mass Dampers” Journal of the Structural Division, Vol. 107, Issue 8, August 1981.
6) Mariana M. Americano da Costa, Daniel A. Castello, Carlos Magluta, Ney Roitman, “On the optimal design and robustness of spatially distributed tuned mass dampers”, Mechanical Systems and Signal Processing, 2021.
7) Jeong Hee Choi, Chae Hun An, “An Active Tuned Mass Damper for Vibration Reduction of Ultra-High-Precision Equipment, Journal of the Korean Society for Precision Engineering”, 38, 1, pp. 11-17, 2021.
8) Sadegh Etedali, “Ranking of design scenarios of TMD for seismically excited structures using TOPSIS, Frontiers of Structural and Civil Engineering”, 14, 6, pp. 1372-1386, 2020.
9) I Nishimura1, T Kobori1, M Sakamoto1, N Koshika1, K Sasaki1 and S Ohrui1, “Active tuned mass damper”, Smart Materials and Structures, Volume 1, Number 4, 1996.
10) Nigdeli, S.M., Bekdaş, G. Optimum tuned mass damper design in frequency domain for structures. KSCE J Civ Eng 21, pp. 912–922, 2017.
11) John R. Sladek and Richard E. Klingner, “Effect of Tuned-Mass Dampers on Seismic

Response", Journal of Structural Engineering, Vol. 109, Issue 8, 1983.

12) C. C. Chang, Henry T. Y. Yang, "Control of Buildings Using Active Tuned Mass Dampers", Journal of Engineering Mechanics, Vol. 121, Issue 3, 1995.

13) S. Tuhta, F. Günday, and M. O. Warayth, "The Effect of GFRP Steel Silo on Modal Parameters Using Finite Element Method," International Journal of Innovatıons in Engineering Research and Technology, vol. 8, no. 7, pp. 41–46, Jul. 2021.

14) S. Tuhta and F. Günday, "Analytical Modal Analysis of RC Building Retrofitted with CFRP using Finite Element Method," International Journal of Latest Technology in Engineering, Management Applied Science, vol. 9, no. 2, pp. 78–82, Mar. 2020.

15) S. Tuhta, F. Günday, And A. Alihassan, "The Effect of CFRP Reinforced Concrete Chimney on Modal Parameters Using Finite Element Method," International Journal of Innovations in Engineering Research and Technology, vol. 7, no. 2, pp. 1–6, Feb. 2020.

16) S. Tuhta, F. Günday, and N. C. Pehlivan, "Investigation of Cfrp Retrofitting Effect on Masonry Dome on Bending Moment Using Finite Element Method," International Journal of Innovatıons in Engineering Research and Technology, vol. 6, no. 6, pp. 18–22, Jun. 2019.

17) S. Tuhta, F. Günday, H. Aydin, and M. Alalou, "Modal Analysis of Model Steel Bridge by Finite Element Method," presented at the 2nd International Eurasian Conference on Science, Engineering and Technology (EurasianSciEnTech 2020) , 2020.

18) S. Tuhta, F. Günday, H. Aydin, and M. Alalou, "Modal analysis of steel test structure reinforced with cable elements by finite element method," presented at the 2nd International Eurasian Conference on Science, Engineering and Technology (EurasianSciEnTech 2020) , 2020.

19) F. Günday, "Comparison of Dynamic Parameters of Scaled Concrete Bridge by Analytical and Operational Modal Analysis," International Journal of Innovatıons in Engineering Research and Technology, vol. 8, no. 5, pp. 166–175, May 2021.

20) F. Günday, "Analytical and Experimental Modal Analysis of GFRP Benchmark Structure Using Shake Table," International Journal of Innovatıons in Engineering Research and Technology, vol. 8, no. 5, pp. 157–165, May 2021.

21) S. Tuhta, "Analytical and Experimental Modal Analysis of Model Wind Tunnel using Microtremor Excitation," Wind & Structures, vol. 32, no. 6, pp. 563–571, Jun. 2021.

22) S. Tuhta, "Analytical and Experimental Investigation on the Modal Properties of Scaled Concrete Retaining Wall," JournalNX- A Multidisciplinary Peer Reviewed Journal, pp. 0–0, May 2021.