International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-3, September 2019

Seismic and Wind Analysis of Regular and Irregular RC Structures with Tuned Mass Damper

Deepak P. Kadam, Atul B. Pujari, Vipul N. Khosla

Abstract - Latest trend in the development high rise structure demanding taller and lighter structures, which are progressively adaptable with very low damping ratio. As the structures developing vertically, they are ending up all the more affecting by powerful excitation forces, for example, wind and seismic forces. For the more safety of structure and inhabitant's solace, the vibrations of the tall structures become a major issue for both structural designers. So as to control the vibration, various methodologies are proposed out of the few systems accessible for vibration control. Out of numerous methods, TMD has been observed to be increasingly powerful in controlling the dynamic forces caused due to seismic and wind excitations. In this paper, the adequacy of TMD in controlling the dynamic reaction of structures and the impact of different ground movement parameters on the seismic viability of TMD is researched.

Essentially, a TMD is a vibratory subsystem appended to a bigger scale host structure so as to lessen the dynamic reactions. The frequency of damper will tuned to essential structure's frequency, so when frequency is high, the damper will results to resonate out of phase along with structural movement. The objective of this work is to study the impact of TMD on the dynamic forces brought about by seismic tremor and wind excitations in standard just as unpredictable in tall RC building structures. For that three 22 story RC building structures are considered with a similar arrangement out of which one ordinary regular structure and the other two are irregular RC structures are demonstrated in Etabs. In irregular RC structures, Stiffness irregularity and torsional irregularity are considered.

For assessing seismic and wind reactions of structures, time history analysis, and static analysis used, with and without the tuned mass damper in ETABS. The outcomes acquired from the investigation of three 22 story RC structures with and without tuned mass damper are compared.

Keywords: Tuned Mass Damper, Dynamic Responses, Time history Analysis, Etabs

Manuscript published on 30 September 2019
* Correspondence Author

Deepak P. Kadam*, Post graduate student Department of Civil Engineering, KJ College of Engineering & Management Research, Pune-411048, India. Email: Deepakkadam01@gmail.com

Dr. Atul B. Pujari, Associate Professor Department of civil engineering, KJ College of Engineering & Management Research, Pune-411048, India. Email: Pujari.atul@gmail.com

Vipul N. Khosla, Post graduate student Department of Civil Engineering, KJ College of Engineering & Management Research, Pune-411048, India. Email: Vipul.khosla.vk@gmail.com

© The Authors. Published by Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP). This is an open access article under the CC-BY-NC-ND license http://creativecommons.org/licenses/by-nc-nd/4.0/

I. INTRODUCTION

With the fast economic and infrastructural development, common structures, for example, elevated structures, towers, and long-span bridges are planned with an extra adaptability, which lead to susceptibility to dynamic excitation. In this way, these adaptable structures are vulnerable to endure abnormal amounts of vibration under the activities of wind or tremor. The behavior of a structure during tremors depends fundamentally on its general shape, size and geometry, alongside the how quake powers are shaking the ground. Structures comprising of asymmetric dispersion of strength, stiffness and mass endure serious harm during quakes.

In the modern era of tall building structures, a large portion of the structures are engaged with architectural importance and it is profoundly difficult to design with ordinary shapes. These irregularities are in charge collapse of buildings under the activity of dynamic responses. Thus, enough research is required to accomplish extreme execution even with a poor setup. In the modern era of tall building structures, a large portion of the structures are engaged with architectural importance and it is profoundly difficult to design with ordinary shapes. These irregularities are causes structural collapse under the activity of dynamic responses. Thus, enough research is required to accomplish extreme execution even with a poor setup. More often than not these structures are having low natural damping. So to increment in damping limit of structural systems, or by considering the other mechanical devices to expand the damping limit of the structures is normal in the new trend of tall structures. In any case, it ought to be made with a legitimate routine practice to plan the damping limit into a structural system while designing the basic systems.

There are numerous strategies which have been utilized to control structural vibration and many other techniques proposed which are offering the possibility of improvement in the effectiveness of structures. The selection of a specific sort of vibration control system is governed by various components which incorporate efficiency, compactness and weight, capital cost, operating cost, maintenance requirements and safety. The tuned mass dampers (TMD) have been broadly utilizing the vibration control in basic designing. As of late, TMD system is getting to be prominent to decrease in vibrations of tall structures and other civil structures. The frequency of damper is tuned to essential structure's frequency so that at whatever point that frequency got energized, the damper will resonate out of phase with the structural deflection.

A. STRUCTURAL IRREGULARITY

The irregularities due to the irregular dispersal of mass, stiffness, and strength are the causes of serious harms to structures which causes excessive floor rotations and translations. Additionally, the torsional effect could essentially enhance the seismic responses of structures.

Hence, the design of irregular structures needs some special care and improvement of member sizes in the areas of Irregularity. The plan configuration of the structure has a substantial impact on the seismic reaction of the structure in terms of story displacement, drift, and story shear demands.

In this way, choices on design method at the initial stages is significant. Many of the building structures can have irregularities in both the plan and elevation. There are various types of structural irregularities given in IS 1893-2016. Out of those irregularities considered types irregularities are following,

a) Stiffness irregularity (Soft storey) - When the lateral stiffness of a storey is less than 70% of any adjacent storey, or less than 80% of the corresponding average stiffness of the three storey above or below.

b) Torsional irregularity – A building is assumed to be torsionally irregular,

When the maximum horizontal displacement of any floor in the direction of the lateral force at one end of the floor is more than 1.5 times its minimum horizontal displacement at the far end of the same floor in that direction.

When the natural time period equivalent to the fundamental torsional mode of oscillation is more than those of the first two translational modes of oscillation along each principal plan direction.

B. TUNED MASS DAMPER (TMD)

A tuned mass damper is a system comprising of a mass, spring, and a damper that is appended to a structure to diminish the dynamic reaction of the structure. The frequency of the damper will tuned to a specific structure’s frequency so when the frequency is energized, the damper will resonate out of phase with the structural movement. The energy is dissipated by the damper’s inertia force acting on the structure. Tuned Mass Damper (TMD) idea was first utilized by Frahm in 1909 (Frahm, 1909) to lessen the moving movement of boats just as ship hull vibrations. The idea of the tuned mass damper (TMD) created back to the 1940s (Den Hartog 1947). This system comprises of a secondary mass with appropriately tuned spring and damping components, which gave a frequency-dependent hysteresis that increase damping in the primary structure.

Based on the explained system we can utilize two kinds of TMD’s:

a) Horizontal Tuned Mass Damper: It is regularly found in slender structures, communication towers and such. This tuned mass damper made out of visco-dampers and leaf springs or pendulum suspension. It decays level and torsional excitations.

b) Vertical Tuned Mass Damper: This type of TMD connected in long span horizontal structures, for example, bridges, walkways etc. Vertical tuned mass damper is mix of loop spring and visco-dampers and it decays vertical vibrations. The two kinds have comparative capacities, however, may be a slight dissimilarity in terms of mechanism. From the field vibration estimations, it has been effectively demonstrated that the TMD is a powerful and possible system to use in structural vibration control against high dynamic forces, as appeared in Figure 1.

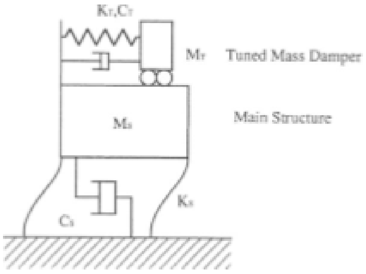


Figure 1. A Damped vibration absorber suggested by Den Hartog

A tuned mass damper (TMD) is located on the top of the structure and through it, consider the consequences for structural response by performing time history analysis with TMD and without TMD in ETABS. Thus, in this project, Vertical Tuned mass dampers utilized in regular and irregular structures by considering most basic circumstances and will look at the outcomes.

C. Objectives

1. Analysis of symmetrical and non-symmetrical RC structures with tuned mass dampers which are having the same storey.
2. To find the seismic responses (storey drift, storey displacement and base shear) of regular and irregular RC buildings with TMD.
3. To find wind responses (storey drift, storey displacement and base shear) of regular and irregular RC buildings with TMD.
4. To determine the behavior of TMD in buildings with different irregularities and subjected to high lateral forces.
5. Determination of the results achieved from the analysis of G+22 RC structure with TMD.
6. To study the behavior of G+22 RC structures during an earthquake as well as wind with the irregularities in plan and elevation.

II. LITERATURE REVIEW

a) Mr. Ashish A. Mohite, Prof. G.R. Patil (2015), “Earthquake Analysis of Tall Building with Tuned Mass Damper”: Conducted a product investigation of tuned mass damper (TMD) is set over structure and through it to consider its consequences for interstorey drift, story displacement and base shear by performing analysis with and without the tuned mass damper in ETABS. Investigation of symmetrical moment resisting frame (MRF) with 10,12,14,16,18, and 21 story three dimensional models with tuned mass damper and without tuned mass damper by utilizing FEM based software ETABS. These thoughts were plainly clarified in this paper.

b) Vipin V. Halde et al (2015),”Analysis on Behavior of Soft Storey in Structure”: They discussed about in tall structures soft story development considering similar features because of space occupancy considerations. Soft story decreases the stiffness of the lateral load resisting system and a dynamic breakdown will be unavoidable in an extreme tremor for such structures. This storey containing the solid section, they unable to give sufficient shear resistance, consequently harm hance, collapse are regularly seen in soft story structures during the quake.

c) Balakrishna G.S et al (2014),” Seismic Analysis of Building Using Two Types of Passive Energy Dissipation Devices”: In their paper, they introduced about improvement in seismic responses of structures in tremor-prone zones, by utilizing passive energy absorbing devices. Here a 6 storeyed residential structure is examined in SAP2000 v14, by utilizing Tuned Mass Dampers (TMD) and with no damper. Tuned Mass Dampers with mass ratio of 2%, 3% and 5% discussed in this paper. Non-Linear Time History Analysis was done by applying the Bhuj seismic tremor.

d) Thakur V M et al (2012), “Seismic Analysis of Multistoried Building with TMD (Tuned Mass Damper)”: This paper clarifies about TMD utilized in a soft story which is built at the top of the structure. A six storied structure with rectangular shape is considered and examination is finished by FE programming SAP 2000 by utilizing direct integration approach. TMDs with rate masses 2% and 3% are utilized. Three recorded time histories of seismic tremors are used for the investigation. Correlation between the structures with TMD and without TMD is performed.

III. METHODOLOGY

The tuned mass damper is located on the top of the structure comprises of a mass, spring and a damper. By placing the TMD centrally and top of structures, the torsional reaction of the structure may likewise be controlled. Time history analysis is performed to decide seismic responses of structure. For time history analysis, ground movement information recorded during seismic tremor happened in Loma Prieta California has been taken. For wind investigation, wind static analysis is used for getting results.

In the present work Tuned mass damper (TMD) is set on top of the structure and through it, to determine its effectiveness on Storey drift, storey displacement and base shear in ETABS.

IV. MODELING AND ANALYSIS

In this project one regular and two different irregular models are taken. Two irregular models are with two different irregularities viz. Stiffness irregularity and torsional irregularity. Following are material properties, sizes of elements (beams, columns, slabs), seismic and wind parameters considered this project.

A. Material and section properties:

Concrete grade: M30

Steel grade: HYSD500

Beam- 450X750 MM, Column- 600X900 MM, Slab thickness- 250 MM

B. Load calculations:

Dead load and live load calculation on slab (As Per is 875-2015 Part-1&Part-2 clause 3.1 Table 1):

Dead load calculation (from IS 875 part-1):

Dead Load = 1.5 KN/m2

Live Load = 2 KN/m2

a) Earthquake load (IS-1893-Part: 1-2016):

The building location where seismic Zone is IV with factor 0.24. Since it is a residential building, which is having importance factor 1.2. A Lateral force resisting system in which RC SMRF with response reduction factor (R) 5 is taken. Project building is located on soft soil site.

For time history analysis, Fast Nonlinear Analysis Method is used to get accurate results. Ground motion data of Loma Prieta earthquake is taken which is having earthquake magnitude of 6.9 Mw, a maximum Modified Mercalli intensity of IX (Violent).

b) Wind load calculations:

Wind loads is calculated in accordance with IS 875: Part 3. Project is considered to be located in location where basic wind speed is 47 m/sec with fairly level topography with mean return period of 50 years is considered for which the k1 factor will be 1. Since the project building is considered to having some surrounding buildings of sizes up to 10 m in height with or without a few isolated tall structures, hence it will be in terrain category is III.

C. Modeling in ETABS 2016- version 16.2.0

a) Regular model:

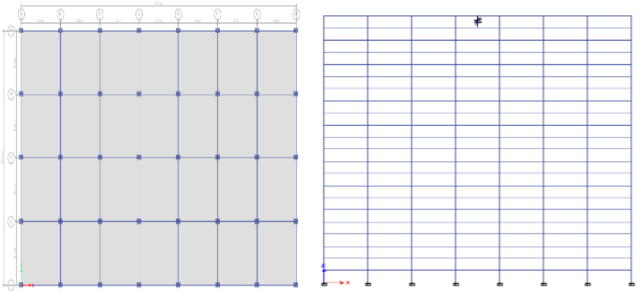


Figure 2. Model of regular RC structure with TMD

b) Soft storey model:

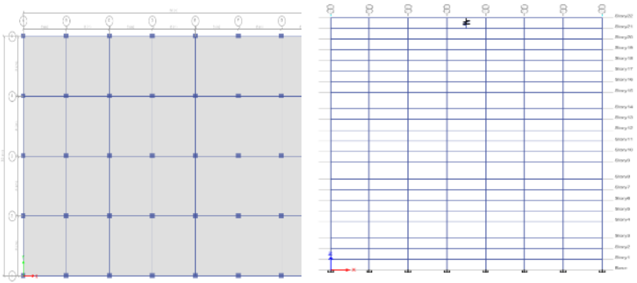


Figure 3. Model of soft storey RC structure with TMD

c) Torsionally irregular model:

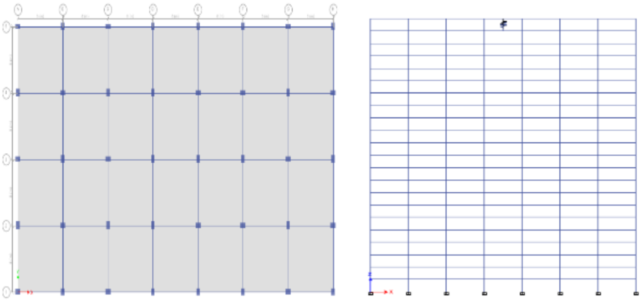


Figure 4. Model of torsion irregularity RC structure with TMD

D. Determination of the Optimum TMD –

One TMD is successful in diminishing powerful dynamic forces of just a single vibration mode of the structure. Despite the fact that a structure has numerous vibration modes as a general rule, fundamental properties of TMD can be obviously discussed utilizing an improved 2-DOF model comprising of the primary structure and the TMD system.

Mass of tuned mass damper is calculated from total modal mass participated in first mode. Mass of TMD is 3 to 5 % of Modal mass participated in first mode. Usually this percentage is on higher side in case of high rise structures. Hence, we will consider appropriate mass ration based on mass participation.

Model mass participated in first mode of all three models are as follows,

Regular Structure $M_1 = 331503.72$ KN

Soft Storey Structure $M_2 = 357368.919$ KN

Torsionally Irregular Structure $M_3 = 307915.75$ KN

From above, mass of TMD considered as appropriate percentage of mass of average of above masses.

Also, the length of pendulum will be calculated by using a simple equation,

$$T = 2\Pi\sqrt{\frac{K}{M}} = 2\Pi\sqrt{\frac{M}{Mg/L}} = 2\Pi\sqrt{\frac{M}{L}}$$

From above formulation, length of pendulum can be decided.

V. RESULTS AND DISCUSSION

A. Regular structure

a) Displacement-

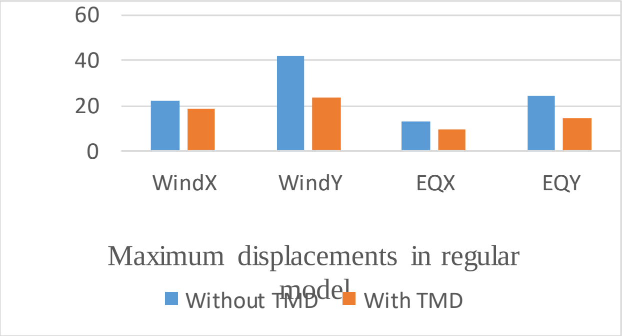
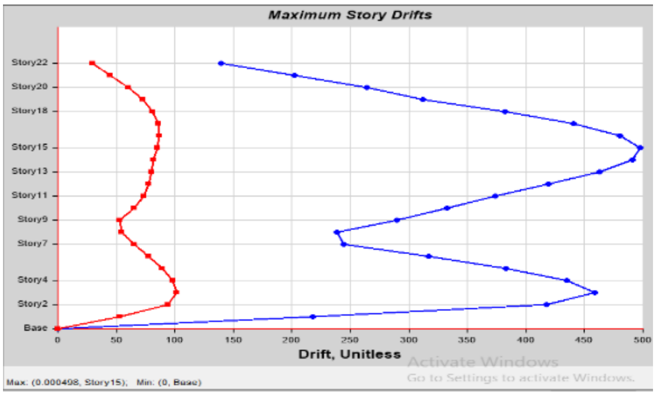


Figure 5 . Maximum horizontal displacement due to lateral force

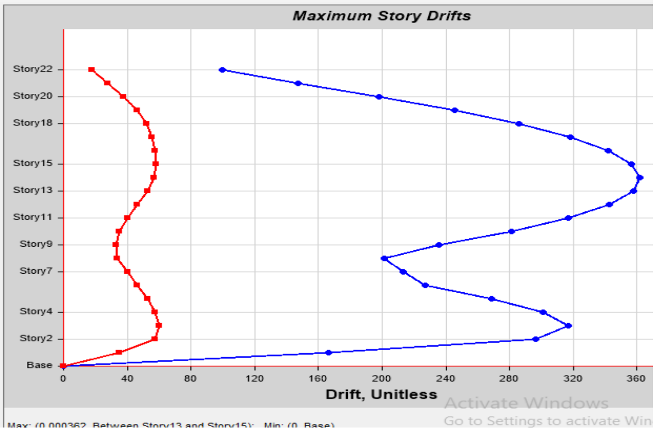
b) Drift-

It is observed that the storey drift values are considerably high for the 13 to 15th floor. Storey drift limitation given in IS 1893 (Part I): 2016 storey drifts is limited to 0.004 times the storey height.



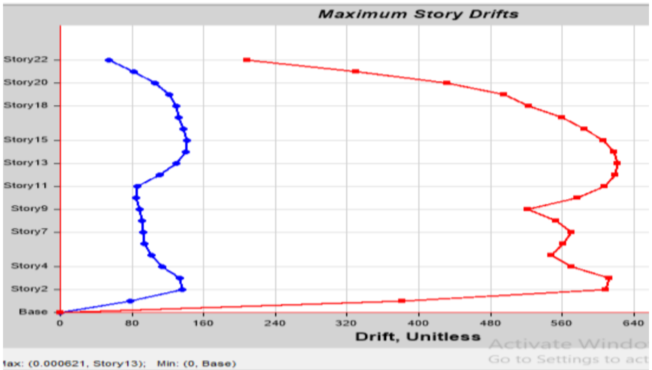
Max: (0.000498, Story15); Min: (0, Base)

Figure 6. Drift without TMD in X direction



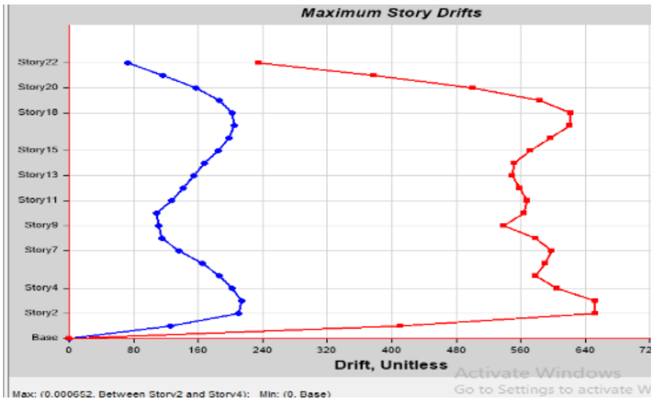
Max: (0.000362, Between Story13 and Story15); Min: (0, Base)

Figure 7. Drift with TMD in X direction



ax: (0.000621, Story13); Min: (0, Base)

Figure 8. Drift without TMD in Y direction



Max: (0.000652, Between Story2 and Story4); Min: (0, Base)

Figure 9. Drift with TMD in Y direction

c) Base shear:

Load Case	Without TMD	With TMD
Wind X	3579.11 kN	3188.78 kN
Wind Y	5150.40 kN	4820.85 kN
EQ X	2165.51 kN	2230.35 kN
EQ Y	3142.28 kN	2904.33 kN

Table 1. Base shear of regular structure

B. STRUCTURE WITH SOFT STOREY:

a) Displacement:

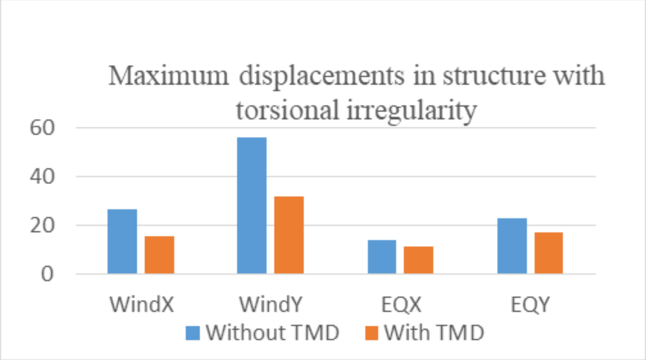


Figure 10. Maximum horizontal displacement due to lateral force

c) Drift:

The storey drift limitation given in IS 1893 (Part I): 2016 each storey drifts is limited to 0.004 times the storey height.

In structure without TMD, maximum storey drift is 0.0053 in X direction and 0.00643 in Y Direction. But in structure with TMD it is seen that maximum storey drift is X direction is slightly reduced to 0.00422 and 0.000362 in Y direction.

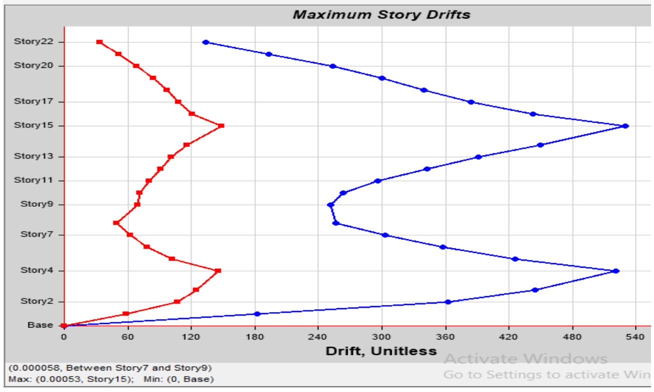


Figure 11. Drift without TMD in X direction

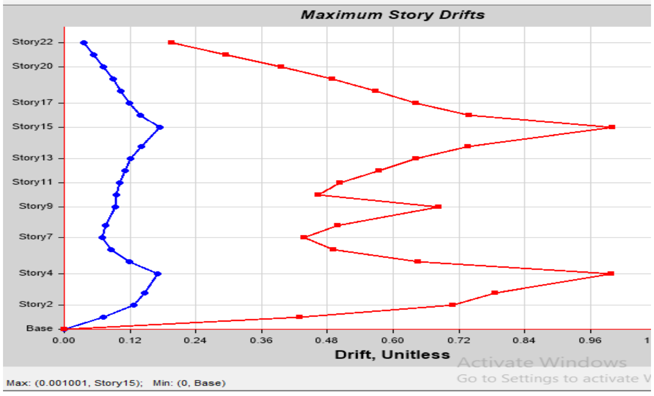


Figure 12. Drift with TMD in X direction

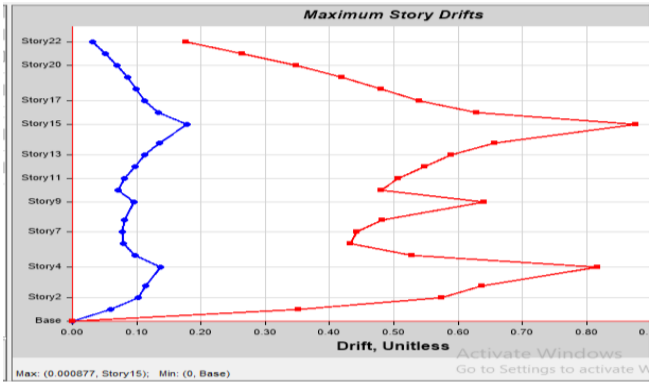


Figure 13. Drift without TMD in Y direction

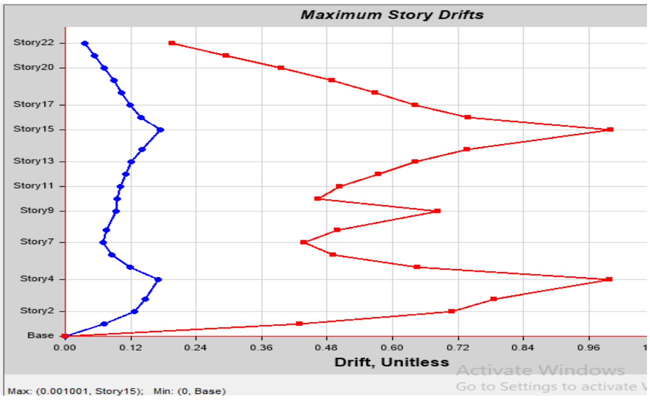


Figure 14. Drift with TMD in Y direction

d) Base shear:

Table 2. Base shear of regular structur

Load Case	Without TMD	With TMD
Wind X	3934.33 kN	3410.78 kN
Wind Y	5150.40 kN	4820.85 kN
EQ X	2389.65 kN	1882.71 kN
EQY	2981.81 kN	2583.39 kN

C. Structure with torsional irregularity:

a) Displacement:

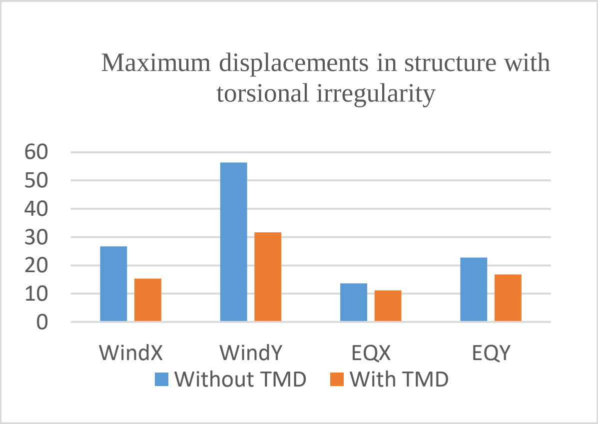


Figure 15. Maximum horizontal displacement due to lateral force

b) Drift:

The storey drift limitation in IS 1893 (Part I): 2016 each storey drifts is limited to 0.004 times the storey height.
In structure without TMD, maximum storey drift is 0.00406 in X direction and 0.00648 in Y Direction. But in structure with TMD it is seen that maximum storey drift is X direction is slightly reduced to 0.00387 and 0.00583 in Y direction.

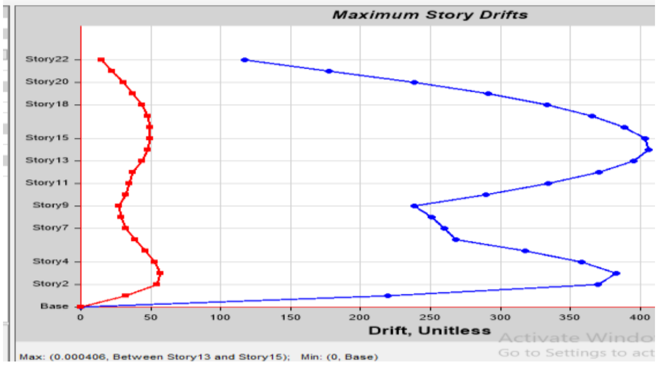


Figure 16. Drift without TMD in X direction

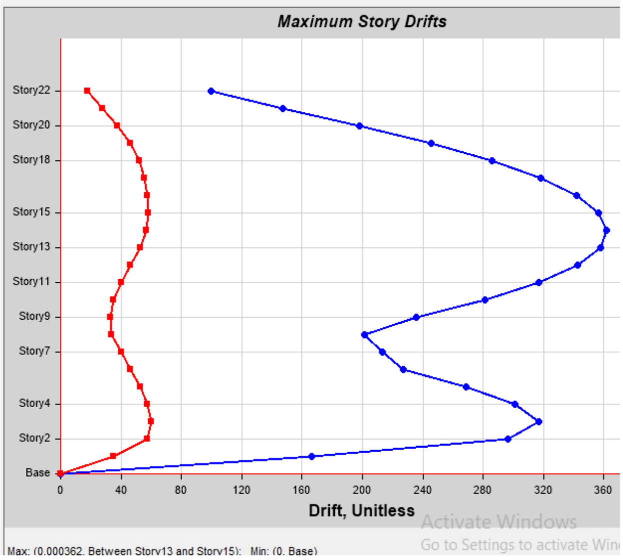
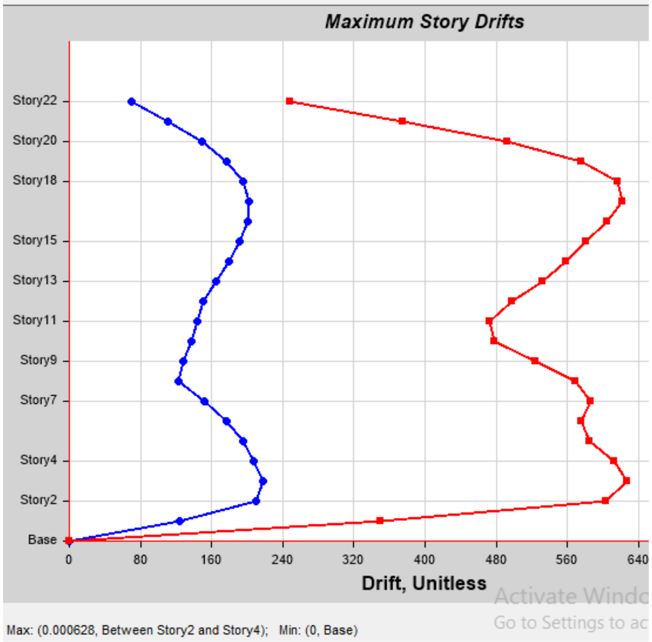


Figure 17. Drift with TMD in X direction



`Figure 18. Drift without TMD in Y direction

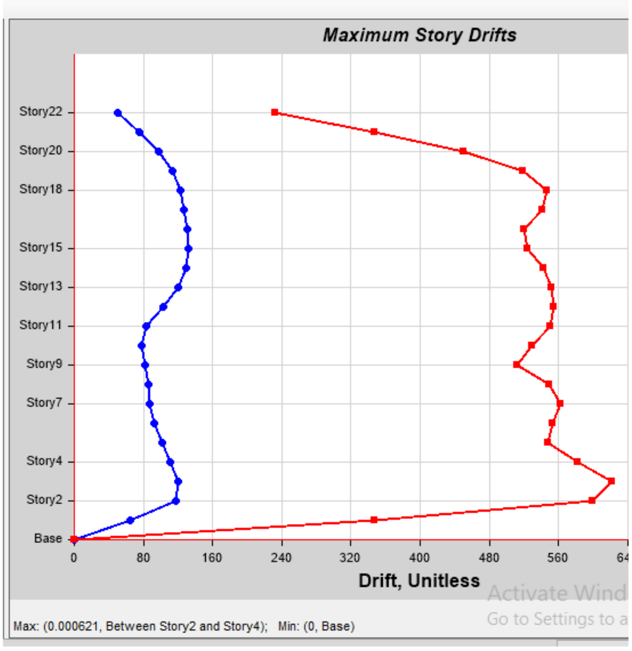


Figure 19. Drift with TMD in Y direction

c) Base shear:

Table 3. Base shear of regular structure

Load Case	Without TMD	With TMD
Wind X	3597.11 kN	3164.23 kN
Wind Y	5734.25 kN	4953.86 kN
EQ X	2307.86 kN	1657.14 kN
EQY	3340.74 kN	2943.89 kN

Retrieval Number: B3672078219/19©BEIESP
DOI:10.35940/ijrte.B3672.098319
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

VI. DISCUSSION:

The maximum reduction in storey displacement is approximately 20 to 25%. In some structures with irregularities like stiffness irregularity, storey displacement was increasing extensively but after using tuned mass damper in those structures displacement reduced up to some extent. In time history analysis, storey drift crosses the permissible limit given as per IS code but after using TMD in structures drift reduces approximately 30 to 35 %. In case of soft storey structures, storey drift increased drastically at some storeys but that is also reduced up to 15 to 20 % by using TMD. Fundamental time period reduction by 4 to 5 % is also observed.

VII. CONCLUSION:

Based on present analysis study and explored literature review the accompanying conclusion can be drawn:

1. Performance of building in seismic forces, after application of tuned mass damper is greatly improved when we provide TMD to top storey of structure.
2. In case of structures with various irregularities, performance of TMD is better in reducing excessive deflection, drift, time period etc.
3. Regular structures but with some improper mass distribution also can give better results in dynamic analysis.
4. Due to use of extra mass in structure in the form of TMD, drastic changes in base shear is not observed but the time period is reduced up to some extent.
5. TMD is observed to be very effective in structures having torsional irregularities.
6. Application of TMD damper reduces large amount of displacement of the structure. Hence it will be concluded that the TMD can be used to control vibration of the structure.
7. Absolute reduction in displacement of the structure causes less ductility requirement to resisting earth-quake forces.

REFERENCES

1. Mohite, A. A., and Patil, G.R. “Earthquake Analysis of Tall Building with Tuned Mass Damper” IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 22781684, p-ISSN: 2320–334X PP 113-122, 2015.
2. Suryawanshi, Y. R., and Rahane, A. S. “Study of Tuned Mass Dampers System as Vibration Controller in Multistoried buildings” © 2012 IJAIR. ALL RIGHTS RESERVED ISSN: 2278-7844, 2012.
3. V.M. Thakur, and P.D. Pachpor, Seismic Analysis of Multistoreyed Building with TMD (Tuned Mass Damper), International Journal of Engineering Research and Applications, Vol. 2, Issue 1, 2012, 319-326, 2012.
4. Khan, W., Akhtar, S., and Hussain, A. "Non-linear Time history analysis of tall structure for seismic load using damper", International Journal of Scientific and Research Publications, Volume 4, Issue 4, 2013.
5. Webster, A.C., and Vaicaitis, R. “Application of Tuned Mass Dampers to Control Vibrations of Composite Floor Systems” Engineering Journal, pp116-124, 2003.
6. KIM, J., And LEE, Y.C. "Dynamic Analysis of multystoried Regular Building", IOSR Journal of Mechanical and Civil Engineering” (IOSR-JMCE), e-ISSN: 2278-1684, p-ISSN: 2320334X, Volume 11, Issue 1 Ver. II , PP 37-42, 2008.
7. D’Ambrisi A., De Stefano M., Tanganelli M., Viti S. (2013), “The Effect of Common Irregularities on the Seismic Performance of Existing RC Framed Buildings”, In: Lavan O., De Stefano M. (eds) Seismic Behaviour and Design of Irregular and Complex Civil Structures. `‘‘’Geotechnical, Geological and Earthquake Engineering, vol 24. Springer, Dordrecht.
8. Kareem A., Bernardini E., Spence S.M.J. (2013) “Control of the Wind Induced Response of Structures”. In: Tamura Y., Kareem A. (eds) Advanced Structural Wind Engineering. Springer, Tokyo.
9. D.M. Deaves., (October 14, 1991) “Analysis of gust factors for use in assessing wind hazard”, Journal of Wind Engineering and Industrial Aerodynamics, 45 (1993) 175 188 175 Elsevier.
10. Daniel Y., Lavan O. (2013), “Allocation and Sizing of Multiple Tuned Mass Dampers for Seismic Control of Irregular Structures”. In: Lavan O., De Stefano M. (eds) Seismic Behaviour and Design of Irregular and Complex Civil Structures. Geotechnical, Geological and Earthquake Engineering, vol 24. Springer, Dordrecht.
11. Chien Liang. Lee, (2006) “Optimal Design Theories and Applications of Tuned Mass Dampers”. Engineering Structures Volume 28. Elsevier, Taiwan.

IS Codes:

1. Indian Standard Code, Criteria for Earthquake Resistant Design of Structures (IS 1893-Part 1-2016).
2. Indian Standard Code, Design Loads (Other Than Earthquake) For Building and Structures (IS 875-Part 3-2015).
3. Indian Standard Code, Design Loads (Other Than Earthquake) For Building and Structures (IS 875-Part 1 & 2-1987).

AUTHORS PROFILE

Deepak Poonamchand Kadam was born on 10th September 1995 at Solapur, Maharashtra, India. He is pursuing Master of Engineering in structures from KJ College of engineering and management research affiliated to Savitribai Phule Pune University situated in pune, India. He has completed his Bachler of civil engineering from Jaihind college of Engineering Pune.
Email- Deepakkadam01@gmail.com

Dr.Atul B. Pujari, was born in 2nd May 1983 at Latur, Maharashtra, India. He is a Research Scholer in Structural Engineering Department, Veermata Jijabai Technological Institutes, Mumbai, India. He Completed M. Tech Structures from same institute. Pujari’s Research interest includes, Progressive collapse analysis of structures and seismic Performance of Structures. He is an associate Professor Department of civil engineering, KJ College of Engineering & Management Research, Pune-411048, India. Email- Pujari.atul@gmail.com

Vipul N. Khosla was born on 13th October at Akola, Maharashtra, India. He is pursuing Master of Engineering in structures from KJ College of engineering and management research affiliated to Savitribai Phule Pune University situated in pune, India. He has completed his Bachler of civil engineering from Anantrao Pawar College of engineering and research, Pune. Email- Vipul.khosla.vk@gmail.com