VIBRATION CONTROL OF INELASTIC 3D STRUCTURE WITH TUNED MASS DAMPER

Hariprasad.T.R. 1, Abhilash.P.P. 2
1 (Structural Engineering, Sreepathy Institute of Management and Technology, Vavanoor, India, hariprasadtr92@gmail.com)
2 (Department of Civil Engg, Sreepathy Institute of Management and Technology, Vavanoor, India, abhiaie@simat.ac.in)

Abstract—Structural engineers are searching for new techniques to minimize the lateral load effects on structures. In order to that, vibration control of structures using several systems is popular now. Tuned mass damper (TMD) is one of the passive control system using to reduce the vibrations of structure. Damping ratio is the one of the parameter of TMD and it is considered as the same as that of the structure. In this paper, the effect of TMD was studied with different mass ratios and TMD configurations. This research was made to study the simplification of using TMD for controlling vibration of structure in finite element software under a harmonic analysis. A six storied structure made up of RCC is considered for the analyses. Analyses were done by FE software SAP 2000 by using direct integration approach. A non linear Time history analysis was carried out and TMDs were placed in the top two stories with various configurations. Moreover, TMDs with mass ratios 2.5%, 5%, 7.5% and 10% were also considered. Comparison was done between the building with TMD and without TMD. Finally Results of time periods, base shear and maximum displacements were compared using all test models.

Keywords—Dynamic responses, free vibration characteristics, Non-linear time history analysis, Optimum parameters, TMD.

1. INTRODUCTION

Tall buildings dominate the skylines of major financial centers of the world, where high land costs and dense population have driven the demanding construction of tall commercial and residential accommodations. As a result, a number of landmark tall building projects are currently under construction in major cities, and the height record of world’s tallest building has almost doubled in 30 years. The increases in building height are often accompanied by more flexibility and insufficient inherent damping, magnifying the building’s susceptibility to wind-induced vibration, particularly in typhoon-prone cities. The wind-induced dynamic response of such buildings needs to be considered in terms of loading and deflection during extreme storms and in terms of the effects of building motion on occupant comfort during typhoons and other frequent strong monsoon wind events. Although recent novel developments in structural systems have permitted increased lateral wind loads to be successfully resisted, the wind-induced building responses still have not been efficiently and economically dealt with, potentially causing discomfort to building occupants and posing serious serviceability issues. Consequently, the current design of many tall buildings often includes significantly more materials than are required for structural strength to satisfy occupant comfort requirements.

The present paper focuses on the performance evaluation of tuned mass dampers. The objective is to study the effectiveness of these passive control techniques on vibration control of linear multi storied buildings under various loads, using numerical analysis. TMD is designed for a multi-storied building and their performances are evaluated and compared.

2. REVIEW OF LITERATURE

Some previous studies have conducted on the TMD in previous years. Most of the studies are numerical studies. And some researchers are tested the quality of TMD in 2D and 3D models. The study on “Seismic Analysis of Multistoried Building with TMD” conducted by Thakur V.M and Pachpuri P.D [10] examines TMDs used as soft story which is considered to be made up of RCC, constructed at the top of the building. A six storied building with rectangular shape is considered for analysis. Analysis is done.
by FE software SAP 2000 by using direct integration approach. TMDs with percentage masses 2% & 3% are considered. Three different recorded time histories of past EQ, are used for the analysis. Comparison is done between the buildings with TMD and without TMD. 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.

Bandivadekar T.P and Jangid R.S [5] conducted a study on Mass distribution of multiple tuned mass dampers for vibration control of structures. They different mass distributions like parabolic mass distribution and bell shaped mass distribution and its effect on controlling the dynamic response of the system is reported. To increase the effectiveness of the MTMD system, modified parabolic mass distribution and modified bell shaped mass distribution by skewing the mass distribution is proposed. Optimum parameters for MTMD with optimum mass distribution and main system damping varied as 2% and 5% are presented. Among the various mass distributions proposed in the present study Modified bell shaped mass distribution for MTMD is superior. It was found to be more promising in terms of reducing dynamic response of structure making it more flat and increasing bandwidth of flat region. Also, lower values of damper damping associated with this mass distribution makes system more workable.

Hossein Shad and Azlan Adnan [15], have investigated the effectiveness of Tuned Mass Damper (TMD) in suppressing the displacement response of a 5-storey building under harmonic load. This study is the simplification of using TMD for controlling vibration of structure in finite element software under a harmonic analysis. A 5-story building with TMD simulated in software in order to vibration control of structure. A Spring-mass system instead mass damper located in different level of story. Then displacement response of structure obtained from variety model compared together. From this it can be seen that increasing the mass ratio of the TMD results increment in the displacement response of the structure

Aly Mousaad Aly, Ferruccio Resta, Alberto Zasso [4] in 2008, presented a paper on Active Control in a High-Rise Building under Multidirectional Wind Loads. Active control of a tall building subjected to wind loads is presented in this paper. A 48-story high-rise building (209 m height) equipped with two active mass dampers is used in this research. The structure is subjected to both across-wind and along-wind loads obtained for a rigid model (scaled 1:100) that was tested in the wind tunnel of Politecnico di Milano for two different configurations of the surrounding. The building alone is modelled dynamically using three-dimensional model with a total degrees-of-freedom of 144 (each floor has three degrees-of freedom: two lateral translations and one rotation about the vertical axis). The building considered in this study is a 48-story 209 meters steel tower. Finite elements model (FEM) for the building was done in [Aly et al., 2007]. In this study the in-plane motion of the structure in the x-direction is controlled using both the TMD and ATMD. However, due to the fact that the control of the in-plane response in the x-direction will not affect on the in-plane response of the building in the y-direction, another TMD and ATMD are designed to control the lateral in-plane response in the y-direction. Following that the uncontrolled torsional response is re-added instantaneously to the two lateral responses to give the overall response in the two lateral directions. The building model was tested for a total number of 15 angles of wind attack and the pressure results were transformed into instantaneous pressure coefficients. And the response against wind pressure was recorded. Then TMD and ATMD is introduced and recorded the reduction of vibration. TMD in the x-direction is able to achieve an average reduction in the rms-displacements over all the wind directions and the two configurations by 23.25% while the average reduction achieved by the TMD in the y-direction is 21.3%. The average reductions achieved by the ATMD in x and y-directions are 37.55% and 31.4% respectively. This means that both TMD and ATMD in the x-direction are achieving better performance in reducing rms-displacements than those in the y-direction with a smaller moving mass.

Prashant Pandey, Shrinivas Raydu and Laxmikant Tibude [14] presented a paper on Tuned mass dampers as an energy dissipater. This Study is to control the vibration and drift of the seven storey concrete structure. The Behavior of the TMD subjected to five earthquake data, namely, Imperial, Loma Prieta, Northridge, Oakland, SanFernando was studied under five conditions, numerical simulations are performed to study the structure with and without TMD installed. The building was installed in multiple TMD, single, double and triple TMD as a tuned properly it can reduce the peak response of structures subjected to seismic forces. The optimum parameters of tuned mass dampers considerable reduction in the displacement are mass ratio, damping ratio of structure, and time period of structures. The behavior of the TMD subjected to time history data in an average of reduction the displacement of single TMD is 10.91%, double TMD is 16.55%, and triple TMD is 17.28%. It control maximum displacement of building were triple TMD located, these MTMDs by constructing the building models. It was little bit difficult to construct the models of various structures. Later a Finite Element based software SAP 2000 was introduced in to the field. In the various structural models can be created very easily and various alterations also can be made easily. So the problem of constructing the model was solved and analysis of various structural models can be done by using the software SAP 2000.

3. METHODOLOGY

A six storey RCC framed structure was modelled in the base of a journal which has published in IJERA. Thakur V.M., Pachpor P.D has established his works on “Seismic Analysis of Multi-storyed Building with TMD” in this journal. The structure has single bay in X-direction and four bays in Y-direction in which corresponding bay widths are 4m and 3m. In the case of substructure, 1.5m elevated foundation which assigned as fixed supports below the plinth beams. Moreover, a 100 m slab section was defined and assigned to all stories. M25 grade concrete and HYSD415 Steel
are chosen as material properties and applied loads are self-weight, live load and seismic load as per Indian standards. Earthquake load is significant one and which was applied along X as well as Y directions and analysis was carried out as per IS1893:2000. Location of structure was assumed as Kerala and other earthquake characteristics were selected. For instance, zone IV was chosen as regional characteristic. A nonlinear time history analysis was carried out to get the time response of each vibration mode and the analysis implemented by the help of integrated design software SAP2000.

Modal analysis

The study about the vibration modes of a structure is an important step prior to seismic analysis. Thus modal analysis is the study of dynamics analysis of structures under vibration excitation. It uses the overall mass and stiffness of the structure to find the various periods in which it will naturally resonate. Modal analysis of the 6 storey RC frame structure is done to determine the dynamic parameters like natural frequency, time period, and their corresponding mode shapes under vibration excitation.

Tuned mass damper

A tuned-mass damper (TMD), also known as a pendulum damper, is not really a damper, but rather a pendulum or another gravity-based oscillator which is attached to the structure in such a way that it counteracts the vibration of one or more fundamental modes, thereby reducing the wind and/or seismic response of those modes.

The basic parameters of TMD are mass ratio, damping ratio and frequency ratio. The mass ratio is the parameter which is the ratio between mass of the damper to the mass of the structure. The maximum allowable mass ratio for the TMD is 10%. The damping ratio is a parameter, usually denoted by $\zeta$ (zeta) that characterizes the frequency response of a second order ordinary differential equation. It is particularly important in the study of control theory. It is also important in the harmonic oscillator.

The damping ratio provides a mathematical means of expressing the level of damping in a system relative to critical damping. For a damped harmonic oscillator with mass $m$, damping coefficient $c$, and spring constant $k$, it can be defined as the ratio of the damping coefficient in the system's differential equation to the critical damping coefficient:

$$\zeta = \frac{c}{k}$$

$$\zeta = \frac{\text{actual damping}}{\text{critical damping}}.$$  

Where the system's equation of motion is

$$m\ddot{x} + c\dot{x} + kx = 0$$

And the corresponding critical damping coefficient is

$$c_c = 2\sqrt{km}$$

Or

$$c_c = 2m\omega_n$$

The damping ratio is dimensionless, being the ratio of two coefficients of identical units.

The important feature of TMD is the mass of the damper. According to the TMD design the maximum allowable mass of the TMD is 10% mass of the structure. From the previous studies it is proved that mass of the damper will affect the vibration analysis of the structure. Here in this study TMDs for the mass ratios of 0.25, 0.5, 0.75% and 0.1% are designed and checked.

Then defining of directional properties such as translational stiffness’s along U1, U2, and U3. The linear stiffness along U1 represents axial properties, and should be based on the EA/L value of the hangers, where E is the modulus of elasticity and L is the length of the pendulum. The linear stiffness properties of U2 and U3 are chosen as Mg/L. M is the mass of the damper. The TMD is placed on in the top storey of the structure as two link joints.

TMD configurations

The vibration analysis and comparison is carried out by applying TMDs in different configurations in the steel structure. The arrangement includes single TMD and multiple TMD configurations.

Model of structure from SAP2000
4. RESULTS AND COMPARISON

Modal analysis- time periods

Modal analysis is the study of dynamic properties of structures under vibration excitation. It is the field of measuring and analyzing the dynamic response of structures during excitation. The natural mode shapes and frequencies are determined. It is common to use the finite element method to perform this analysis because it is important to know the way the structure vibrates and to find out if there are any elements with inappropriate dynamic behavior prior to time consuming seismic calculations.

The fundamental time period of the uncontrolled stage is found to be 0.98 s. The structure is designed to be maximum damping, so 10% damping is provided in the present study. And also damping of 2.5%, 5% and 7.5% are also checked. This approach is suitable for calculations based on modal decomposition and therefore is valid for structure with linear behavior. It is clearly understood that the first vibration modes have long periods. Higher frequencies appear deforming mainly the towers.

Time periods of case 1 with various mass ratios

<table>
<thead>
<tr>
<th>Mode</th>
<th>Without TMD</th>
<th>With TMD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mass ratio</td>
<td>0.025</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.67864</td>
<td>1.14176</td>
</tr>
<tr>
<td>3</td>
<td>0.66010</td>
<td>0.73232</td>
</tr>
<tr>
<td>4</td>
<td>0.32334</td>
<td>0.40122</td>
</tr>
</tbody>
</table>

Time periods of case 2 with various mass ratios

<table>
<thead>
<tr>
<th>Mode</th>
<th>Without TMD</th>
<th>With TMD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mass ratio</td>
<td>0.025</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.67864</td>
<td>1.40907</td>
</tr>
<tr>
<td>3</td>
<td>0.66010</td>
<td>0.76979</td>
</tr>
<tr>
<td>4</td>
<td>0.323342</td>
<td>0.42209</td>
</tr>
</tbody>
</table>
After that modal analysis was carried out. As a starting point, non-linear static analysis was performed. After that modal analysis was carried out.

**Modal Analysis Study**

- After the modal analysis study natural frequency and mode shapes were obtained.
- Incorporation of TMD shifted the fundamental frequency. From the modal analysis the first mode time period of structure without TMD (case 1) were found to be 0.98 sec, where as the first mode time period of structure with TMD with 0.025 mass ratios is found to be 1.61 sec i.e. approximately 1.6 times. And by increasing mass ratio to 0.05, 0.075, 0.1 the time period at 1st mode is found to be 2.08, 2.46 and 2.79
- The mass of the TMD directly influences the vibration of the structure. Such that, the frequency decrease with increase in mass ratio.
- Then the TMD configuration can make a difference in the vibration excitation. When the number of damper increases the time period also increased. For example in a mass ratio of 0.1 the time period for the three cases are found to be 2.79, 3.61 and 4.10 respectively.

### 5. SUMMARY AND CONCLUSIONS

The main purpose of this research was the study of dynamic analysis of RC structure with TMD. The efficiency of passive TMD systems was investigated in assuring RC structure. The TMD with various mass ratios and various TMD configurations were tested and result comparison were carried out. As a starting point, non-linear static analysis was performed. After that modal analysis was carried out.

Model analysis proved that time period of the structure increase with increase in the mass ratio. This reveals that the frequency of the structure will be reducing. The time period of 0.9843 obtained in the first mode without TMD. The variation of time period is in a increasing order such as 1.615, 2.08, 2.465, and 2.796 and corresponding mass ratios are 2.5%, 5%, 7.5% and 10%.

### 6. FUTURE SCOPE OF THE STUDY

Damping ratio is another parameter which also influences the TMD. Comparison of models based on maximum base shear and maximum displacement is inevitable. Furthermore, providing multiple Tuned mass dampers and changing the TMD configurations may affect the vibration of the structure. Some parameters are indispensable in the design of structure and they are position in which TMD has to be attached, the number of TMDs and selection of most economical mass ratio

**REFERENCES**

4. Aly Mousaad Aly, Politecnico di Milano, Milano, Italy aly.mousaad@polimi.it Ferruccio Resta, Politecnico di Milano, Milano, Italy ferruccio.resta@polimi.it Alberto Zasso, Politecnico di Milano, Milano, Italy alberto.zasso@polimi.it” Active Control in a High-Rise Building under Multidirectional Wind Loads ” Structures 2008: Crossing Borders
7. Maria Q. Fengt, Associate Member, ASCE, and Akira Mita, Member, ASCE “vibration control of tall buildings using mega subconfiguration” journal of engineering mechanics October 1995
11. IS 800:2002 “Plain and reinforced concrete-code for practice”
12. IS 875:1987(PART 3)”code practice for design loads other than earthquake for buildings and structures”
13. IS 1893:2002 1”code for earthquake design for buildings and structures
14. Prashant Pandey, Shriniwas Raydu and Laksmikant Tibade.”Tuned mass dampers as an energy dissipater”, IJERE 2015