ANALYZING CAPABILITY OF TMD IN REDUCING THE STRUCTURAL VIBRATION INDUCED DUE TO EARTHQUAKE IN SINGLE AND A DOUBLE STOREY FRAME MODEL

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ABSTRACT: There are large numbers of studies on theoretical investigation of behaviour of buildings with tuned mass dampers under various impacts. However, the experimental studies in this area are quite limited. In this thesis, a one-storey and a two-storey building frame models are developed for shake table experiment under sinusoidal excitation to observe the response of the structure with and without TMD. The TMD is tuned to the structural frequency of the structure keeping the stiffness and damping constant. Various parameters such as frequency ratio, mass ratio, tuning ratio etc. are considered to observe the effectiveness and robustness of the TMD in terms of percentage reduction in amplitude of the structure. Then the responses obtained are validated numerically using finite element method. From the study it is observed that, TMD can be effectively used for vibration control of structures.

I. INTRODUCTION

Earthquake is a compartment of structural analysis which involves the computation of the response of a structure subjected to earthquake excitation. This is required for carrying out the structural design, structural assessment and retrofitting of the structures in the regions where earthquakes are prevalent.Now a day number of tall buildings are going on increasing which are quite flexible and having very low damping value to minimize increasing space problems in urban areas. These structures should be designed to oppose dynamic forces through a combination of strength, flexibility and energy absorption such that it may deform beyond elastic limit when subjected to severe earthquake motion. To make these structures free from earthquake and wind induced structural vibration, various techniques has been adopted which can be broadly classified into 4 categories.
(i) Active control, (ii) Passive control, (iii) Semi-active control and (iv) Hybrid control.

II. EXPERIMENTAL STUDY

Tuned mass damper is a low cost seismic protection technique which is implemented in many tall building and tower in the world without interrupting the use of the building. Thus till now various research works have been conducted to discover the effect of TMD to reduce the seismic shaking of the structure numerically. But experimental works under this field is quite limited.
The motive of this study is to reduce the response by attaching a tuned mass damper to the structure under sinusoidal loading and also to obtain the effect of various parameters such as mass ratio, frequency ratio, tuning ratio etc. on response of the structure. Ratio of damper mass to the mass of the structure is known as mass ratio, ratio of excitation frequency to the fundamental frequency of the structure is known as frequency ratio and the ratio of damper tuning frequency to structural frequency is known as tuning ratio.

For this experiment, shaking table test is conducted to study the dynamic behavior of a single and a double frame structure with and without TMD where it is subjected to sinusoidal ground motion. The structure is rigidly attached to the shaking table platform. The weight of the structure may be regarded as concentrated at the roof level. Since a sinusoidal motion consists of a single frequency, it will provide a better understanding of the behavior of TMD-structure system. The fundamental frequency of the structure is determined from free vibration analysis.

Force vibration analysis is carried out by exciting the frame at various frequencies and the response is recorded.Signal study is usually divided into time and frequency domains; each domain gives a different outlook and insight into the nature of the vibration.

Time domain analysis starts by analyzing the signal as a function of time. A signal analyzer can be used to develop the signal. The time history analysis plots give information that helps describe the behavior of the structure. Its behavior can be characterized by measuring the maximum vibration level.Frequency analysis also provides valuable information about structural vibration. Any time history signal can be transformed into the frequency domain. The most common mathematical technique for transforming time signals into the frequency domain is called the Fourier Transform. Fourier Transform theory says that any periodic signal can be represented by a series of pure sine tones. In structural analysis, usually time waveforms are measured and their Fourier Transforms are computed. The Fast Fourier Transform (FFT) is a computationally optimized version of the Fourier Transform. With test experience, one can gain the ability to understand structural vibration by studying frequency data.

Experimental set up:

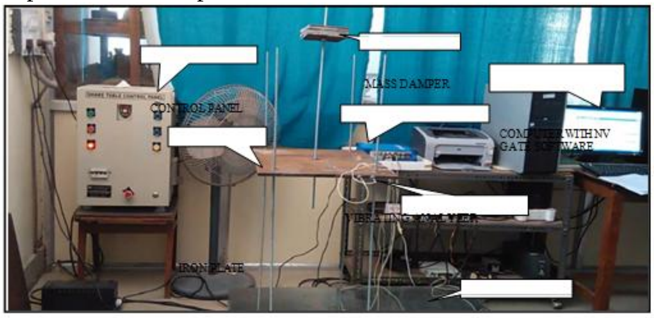

Figure Experimental set up The laboratory equipment consists of,

- A unidirectional shaking table
- Vibrating analyzer
- Control panel
- Accelerometer
- PC loaded with NV gate software
- Frame model with and without secondary mass

Time-domain analysis for single storey frame:

The frame is excited under sinusoidal excitation at various exciting frequencies ranging from 0.18 Hz to 2.97 Hz and the signals obtained are studied both in time and frequency domain which gives two different outlooks to examine the nature of vibration. The maximum displacement and acceleration response for each excitation frequency is obtained from corresponding time domain plots. Displacement and acceleration time history signal of the frame at various mass ratios with and without TMD are plotted for a frequency ratio of 0.8 and 1.0 in figure4.3 to 4.6.

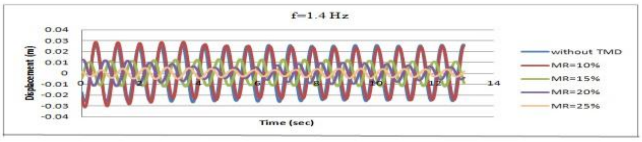

Figure 4.3 Time histories of structural displacement with and without TMD at frequency ratio = 0.8

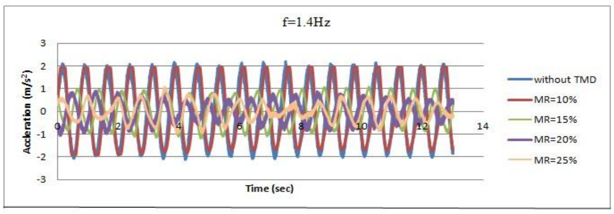

Figure 4.4 Time histories of structural acceleration with and without TMD at frequency ratio = 0.8

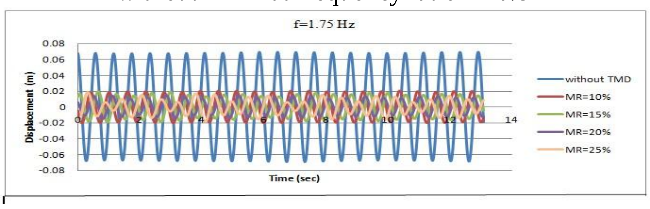

Figure 4.5 Time histories of structural displacement with and without TMD at frequency ratio = 1.0

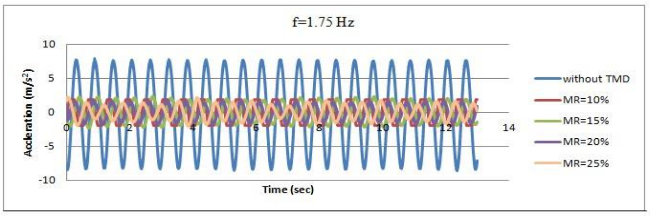

Figure 4.6 Time histories of structural acceleration with and without TMD at frequency ratio = 1.0

In each case, displacement and acceleration response at the top of the frame is observed taking different mass ratios. From figure 4.3 and 4.4, it is observed that for frequency ratio of 0.8, optimum displacement and acceleration response of the frame without TMD are 26 mm and 2.1 m/s^2 which are reduced gradually with increase in mass ratio from 0.10 to 0.25. At mass ratio of 0.25, the value of maximum displacement and acceleration is found to be 5 mm and 0.5 m/s^2 respectively. Figure 4.5 and 4.6 explains the displacement and acceleration response at a frequency ratio of 1.0 (state of resonance). In this case, optimum displacement and acceleration response of the frame without TMD are found to be 70 mm and 8 m/s^2 respectively which are reducing abruptly after attachment of TMD. At mass ratio of 0.25, the value of maximum displacement and acceleration is found to be 10 mm and 1 m/s^2 respectively.From the above observations, it can be concluded that optimum reduction in peak displacement and acceleration for a particular frequency ratio is obtained at high mass ratio and the reduction is maximum when the frequency ratio is unity i.e, when the frame is subjected to a excitation frequency equal to the fundamental frequency of the structure.

Frequency domain analysis for double storey frame:

The frame is excited under sinusoidal excitation containing various exciting frequency ranging from 0.18 Hz to 2.97 Hz and the signals obtained are studied both in time and frequency domain which gives two different outlooks to examine the nature of vibration. The maximum amplitude response for each excitation frequency is obtained for each floor from corresponding time domain plots and presented graphically against the frequency ratio as shown in figure 4.19.

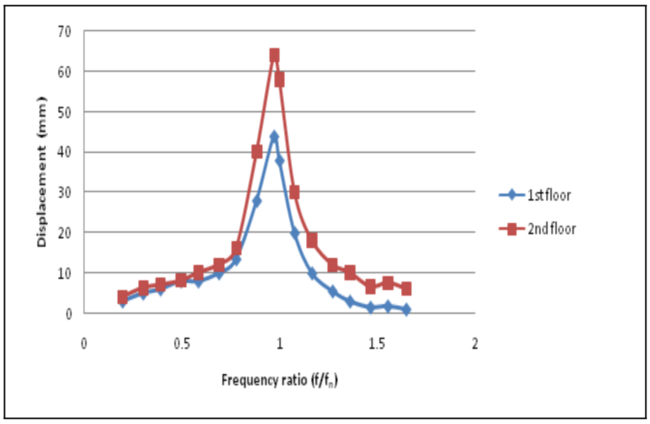

Figure 4.19 Displacement response of two storey frame structure for varying frequency ratios without TMD

The nature of the frequency domain curve obtained for the two storey frame model in figure 4.19 resembles the curve in figure 4.11 obtained for single storey model. It can also be observed that the 1^{st} floor response is always lower than the 2^{nd} floor response.

Effect of frequency ratio on displacement response:

A mass damper is attached at top floor of the primary frame as shown in figure 4.18(b) to observe the reduction in response taking different mass ratio ranging from 0.025 to 0.126. In this study, various frequency ratios starting from 0.1 to 1.7 and mass ratio ranging from 0.025 to 0.126 are considered and the corresponding displacement responses are observed. At each mass ratio the damper is not tuned to the fundamental frequency of the primary structure. At mass ratio of 12.5%, the damper is tuned to the fundamental frequency of the frame (1.8 Hz). Stiffness of damper (k_d) = $m_d w^2$ (in N/m)= 486.08 N/m

With decreasing the mass ratio, the length of the damper is increasing after tuning the damper to the fundamental frequency of the primary model which is not feasible for the experiment. Therefore the damper in tuned at only 12.5% mass ratio. Table 5 shows the different modal frequencies at different mass ratio.

Table 5 Different parameters of single storey frame model

Mass ratio (m_d/m)	Frequency (Hz)	
	1^{st} mode	2^{nd} mode
0.126 (tuned)	1.25	1.9
0.100	1.45	2.05
0.075	1.6	2.4
0.050	1.65	2.7
0.025	1.7	2.7

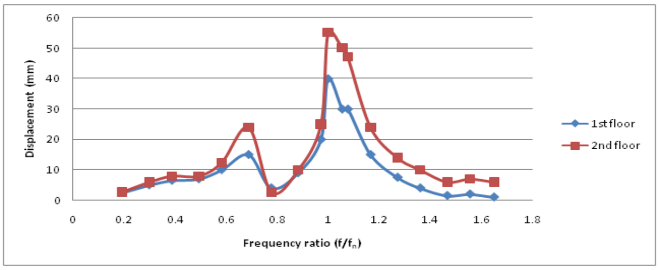

Figure 4.20 Displacement response of two storey frame structure for varying frequency ratios with TMD at a mass ratio of 0.125

The amplitude response of the structure for different forcing frequency ratio with a mass ratio of 0.126 is plotted in figure 4.20 which shows two peaks corresponding to two modal frequency of the secondary structure as observed in previous case. Effect of mass ratio on structural response of a double storey frame model:

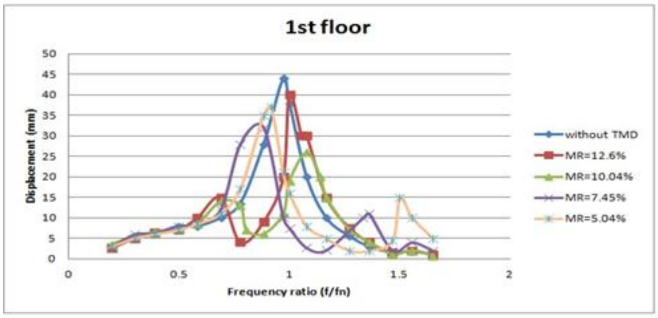

Figure 4.21 First floor displacement response of a two storey frame structure for varying frequency ratios with different mass ratio

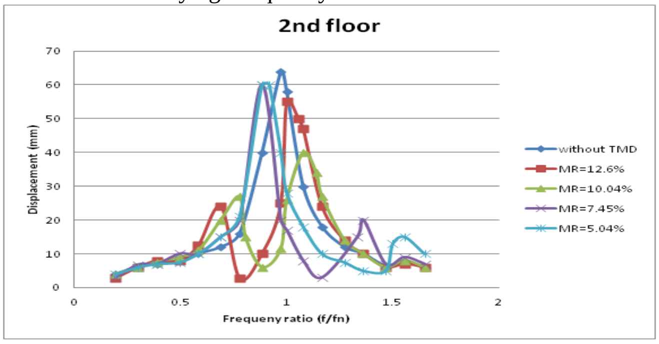

Figure 4.22 Second floor displacement response of a two storey frame structure for varying frequency ratios with different mass ratio

In figure 4.21 and 4.22, at each mass ratio the damper is not tuned to the fundamental frequency of the primary structure. At a mass ratio of 0.125, damper is tuned by fixing the length 43.42 cm. It can be observed that maximum amplitude reduction is obtained when the damper is tuned to the natural frequency of the structure.

III. CONCLUSION

The present study focuses on the capability of TMD in reducing the structural vibration induced due to earthquake. A single and a double storey frame model are examined experimentally with and without TMD to determine the structural response and presented in graphical and tabular forms. Effect of various parameters such as frequency ratio, mass ratio, damping ratio on the amplitude response has been studied with TMD. The results obtained are validated numerically using finite method. Further a four storey and a ten storey RC frame models are studied using Finite element method and STAAD Pro considering various parameters. The experimental and numerical investigation of various frame models under sinusoidal ground motion confirms that the structural response can be considerably reduced to a large extent by a properly designed TMD.

The following conclusions are made from the study.

- When the frame is subjected to sinusoidal ground motion without TMD, amplitude becomes maximum at the point of resonance.
- From the experimental study, it is observed that, after using damper optimum reduction is occurring at a frequency ratio nearer to the point of resonance. That is when the frequency ratio becomes nearer to unity.

- With increase in mass ratio, the peak displacement is going on decreasing up to a particular mass ratio and again it is increasing on further increment of mass ratio.
- It is more effective in reducing the displacement responses of structures when tuned to fundamental (1st mode) frequency of the structure.
- It is more effective to use high damping ratio.

- At a higher beat frequency, beating effect is prominent which diminishes as the forcing frequency approaches to the fundamental frequency and no beating effect is observed at the state of resonance.
- From this study, it can be concluded that properly designed TMD with efficient design parameters such as tuning ratio, frequency ratio and mass ratio is considered to be a very effective device to reduce the structural response.

Future scope for study:

- A linear model is considered in the experimental study. This can be studied by considering a non-linear model.
- In current study the damper mass is placed at the top of the frame model and the reduction in response is observed. A further study can be carried out by placing the damper mass at different floors of the frame structure.
- Effect of mass damper on response reduction can be studied by designing the damper mass in a pendulum shape.
- The study can be further extended by using multiple tuned mass damper (MTMD) tuned with various modal frequencies at different levels.
- A future study can be done with active multiple tuned mass damp.

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