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Experimental evaluation of dynamic properties of controlled building

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ABSTRACT: Nowadays, taller, more flexible, and lighter structure are built due to space constraints. These structures are more sensitive to dynamic loadings like wind, earthquake, etc. Therefore, it is necessary to control the responses of such structures to protect them against hazards. This paper includes the experimental determination of dynamic properties of uncontrolled as well as controlled building. Controlled building includes Tuned Mass Damper (TMD) and Base Isolation System. Two types of Buildings, one represented as Single Degree of Freedom (SDOF) and other as Multi Degree of Freedom (MDOF) system are considered. Dynamic properties like natural frequency and damping ratio are extracted for both types of buildings. It is found that both TMD as well as base isolation system shows increment in damping ratio for SDOF and MDOF systems and thus shows their efficacy.

1 INTRODUCTION

Most structures that are constructed in seismically active areas are subjected to an earthquake at least once during their design life. These structures, when subjected to earthquake, respond dynamically which results into additional stresses in structural members. Thus, understanding the behavior of structures under dynamic loading is quite important.

The response of the structures can be controlled by various means like passive control, active control, and hybrid control systems. Many researchers have found that passive control technique is quite effective and it controls the structural response of the building. Passive control technique includes base isolation, bracings, viscous damper, Tuned Mass Damper (TMD), etc.

To determine the responses of structures with or without control techniques, generally scaled down models of structures are used which are excited using the Shake Table that produces motions similar to earthquake.

2 SINGLE DEGREE OF FREEDOM (SDOF) BUILDING MODEL

A building representing the SDOF system is shown in Figure 1. Dynamic properties of the SDOF system is determined by the free and forced vibration test. Table 1 shows natural frequency of the SDOF system determined analytically by considering shear building and experimentally by determining mass and lateral stiffness of the model.

It is evident from Table 1 that analytical and experimental results show good agreement for lateral stiffness and natural frequency.

Inherent damping ratio of the SDOF building model is extracted by applying logarithmic decrement method (Chopra 2009) to free vibration response. Free vibration response is captured at the top of the building model through piezo-based accelerometer, data acquisition system, and LabVIEW software. Part of free vibration waveform is extracted and peak of each cycle is extracted using the peak detector of LabVIEW. Figure 2 shows free vibration waveform of the SDOF building model.

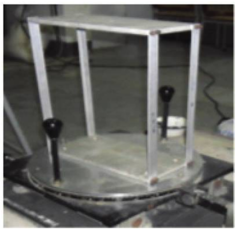

Figure 1. SDOF building model.

Table 1. Stiffness and natural frequency of SDOF model.

Method	Stiffness (N/m)	Frequency (Hz)	Circular frequency (rad/s)
Analytical	2567.54	6.075	38.17
Experimental	2572	6.07	38.13

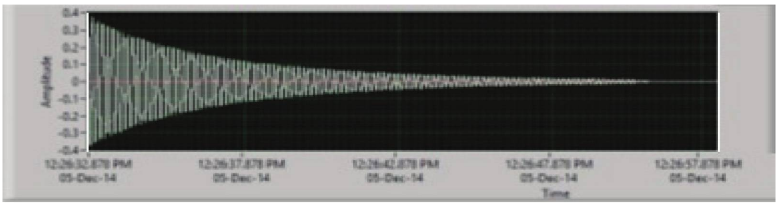

Figure 2. Response of SDOF model under free vibration.

Table 2. Damping ratio of SDOF model with logarithmic decrement method.

Amplitude (g)	Damping ratio							
1.1321	0.0103	0.0106	0.0108	0.0110	0.0112	0.0114	0.0115	0.0117
1.0610	0.0108	0.0110	0.0112	0.0114	0.0116	0.0117	0.0119	
0.9911	0.0112	0.0114	0.0116	0.0117	0.0119	0.0121		
0.9238	0.0116	0.0118	0.0119	0.0121	0.0122			
0.8586	0.0119	0.0121	0.0122	0.0124				
0.7965	0.0122	0.0123	0.0125					
0.7378	0.0125	0.0127						
0.6823	0.0129							
0.6292								

Table 2 summarizes damping ratio that is obtained for SDOF building model by considering subsequent and distance peak of waveforms. Average damping ratio is calculated to be 1.15% of critical damping ratio.

Damping ratio is also evaluated through forced vibration test, where the SDOF building model is harmonically excited by various frequencies. A frequency response plot is determined by capturing acceleration responses through accelerometer and data acquisition system (Panchal 2012). Figure 3 shows the frequency response curve for the SDOF building model. Using half power bandwidth method, the damping ratio extracted is 1.7% of critical damping ratio.

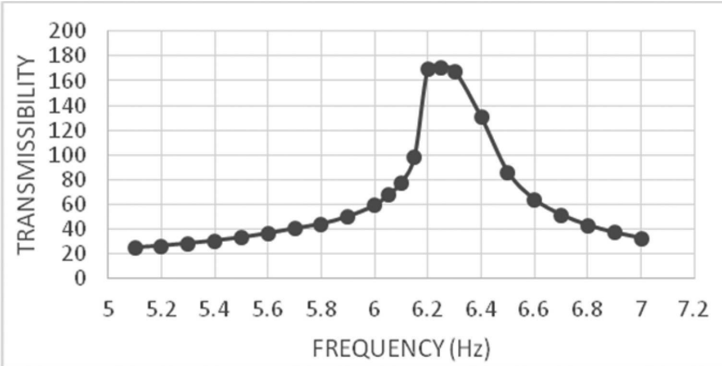

Figure 3. Frequency response curve of SDOF building model.

Figure 4. MDOF building model.

Table 3. Natural frequency of MDOF building model.

Method	Frequency (Hz)	Circular frequency (rad/s)
Analytical	2.9667	18.63

The damping ratio value obtained through free vibration test is observed to be higher as compared with forced vibration test. This may be due to difficulty in capturing the peak of the frequency response curve of forced vibration test.

3 MULTI DEGREE OF FREEDOM (MDOF) BUILDING MODEL

A building represented as MDOF system is as shown in Figure 4. Dynamic properties of MDOF system are also determined by free and forced vibration tests. Table 3 shows the natural frequency of the MDOF system determined analytically by solving the Eigen value problem using MATLAB.

Inherent damping ratio of the MDOF building model is extracted by applying the logarithmic method to free vibration response. Free vibration response is captured at each storey of the building model through a piezo-based accelerometer and data acquisition system and LabVIEW software. Part of free vibration waveform is extracted and peak of each cycle is

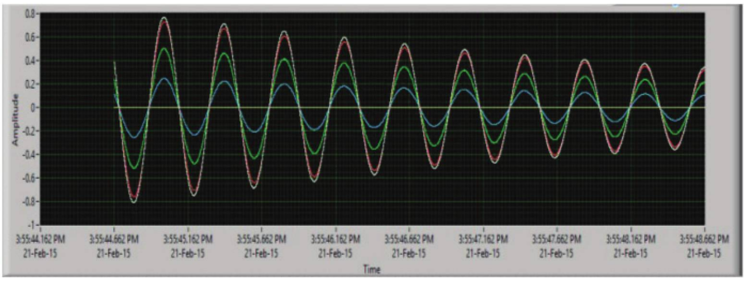

Figure 5. Free vibration response of MDOF system.

Table 4. Damping ratio of the MDOF model with logarithmic decrement method.

Amplitude (g)	Damping ratio						
0.2551	0.0144	0.0130	0.0132	0.0134	0.0139	0.0144	0.0147
0.2330	0.0116	0.0126	0.0131	0.0138	0.0143	0.0147	
0.2166	0.0135	0.0139	0.0145	0.0150	0.0154		
0.1989	0.0142	0.0150	0.0155	0.0158			
0.1820	0.0158	0.0162	0.0164				
0.1647	0.0166	0.0166					
0.1485	0.0167						

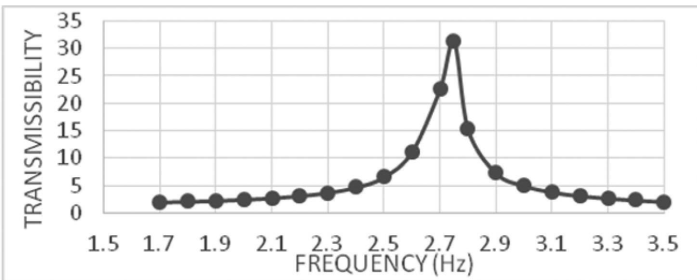

Figure 6. Frequency response curve for MDOF building model.

extracted using a peak detector of LabVIEW. Figure 5 shows free vibration waveform of the MDOF building model. Part of free vibration waveform is extracted and peak of each cycle is extracted using peak detector of LabVIEW. Figure 5 shows free vibration waveform of SDOF Building model.

Table 4 summarizes damping ratio obtained for MDOF building model by considering subsequent and distance peak of waveform. Average damping ratio is calculated to be as 1.54% of critical damping ratio.

Damping ratio is also evaluated through forced vibration test, where in MDOF building model is harmonically excited by various frequencies. A frequency response plot is determined by capturing acceleration responses through the accelerometer and data acquisition system. Figure 6 shows frequency response curve for SDOF building model. Using half power bandwidth method, the damping ratio extracted is 1.45% of critical damping ratio.

4 CONTROLLED RESPONSE WITH TMD

TMD consists of spring, mass, and damper system which is attached to primary mass such that the response of the mass damper is out of phase with the primary mass. Three important

Table 5. Design parameters of TMD for SDOF and MDOF models (Bakre & Jangid 2007).

Design parameters	SDOF model	MDOF model
Stiffness	121 N/m	75 N/m
Mass	90 g	280 g
Mass ratio	4.5%	3%

Table 6. Damping ratio of SDOF and MDOF model with TMD.

	SDOF with TMD	MDOF with TMD
Damping ratio	2.26%	1.8%

Table 7. Time period of SDOF and MDOF with and without base isolation.

	Time period without base isolation (s)	Time period with base isolation (s)
SDOF system	0.167	0.45
MDOF system	0.36	0.769

parameters considered for the design of TMD are mass ratio, frequency ratio, and damping ratio. Referring to previous works by many researchers on TMD, the design parameters for SDOF and MDOF system as shown in Table 5 are calculated.

The above parameters are considered such that TMD for the SDOF system is tuned for the frequency of 6.1 Hz, i.e., natural frequency of SDOF model, and TMD for MDOF system is tuned for 3 Hz, i.e., natural frequency of MDOF model. Models are fixed on the shake table and are subjected to harmonic base excitation with various frequencies. Response is captured at each storey level and at TMD. Damping ratio is evaluated using the half power bandwidth method applied on frequency response. The damping ratio of the SDOF and MDOF models with and without TMD is shown in Table 6.

It is evident from Table 6 that damping ratio has increased for buildings with TMD as compared to uncontrolled (bare) building.

5 CONTROLLED RESPONSE WITH BASE ISOLATION

Base isolation is a technique in which the structure is isolated from the ground with isolators so that energy is not transferred from the ground to the structure. The design of base isolation is carried out such that the time period of isolated buildings shifts to 2.5–3 times the time period of the building without isolation (Sanghani 2004).

An experimental study is carried out to evaluate the reduction in the response of SDOF and MDOF models with base isolation. Models are subjected to free and forced vibration tests and responses are captured using an accelerometer at each floor level. The damping ratio for SDOF and MDOF models is evaluated using the logarithmic decrement method and the half power bandwidth method is tabulated in Table 7.

Table 7 shows the time period of MDOF and SDOF systems with and without base isolation. It is evident from Table 7 that the natural time period of SDOF system has shifted 2.7 times whereas, the natural time period of MDOF system has shifted 2.1 times.

6 CONCLUSION

A building represented using SDOF system and MDOF systems is considered for the present study. Dynamic properties of SDOF and MDOF systems like natural frequency and damping ratio are extracted using free and forced vibration tests.

The following conclusions are derived on the basis of the study:

- Analytical and Experimental results of lateral stiffness show good agreement.
- Damping ratios obtained for SDOF and MDOF building models are 1.15% and 1.45%, respectively.
- Moderate increment in damping ratio is achieved for SDOF and MDOF building models with TMD.

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