INVESTIGATION OF TMD AND TLD PERFORMANCEUNDER EARTHQUAKE EXCITATION, THE CASE OF22-STORY RESIDENTAL BUILDING

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ABSTRACT

Earthquake is a phenomenon that has caused many financial damages and fatalities. Researchers have always tried to decrease the destructive effects of this phenomenon and have presented methods to control structure vulnerability during an earthquake. Passive energy dissipation (PED) devices are a group of structural protective systems which are widely accepted by the engineering community. The basic function of these devices when added to a structure is to absorb a portion of input energy due to earthquake or other dynamic excitations and, as a result, reducing energy dissipation demand on primary structural members. Tuned dampers are a group of passive control systems, which their applications in vibration control of 22-DOF building under seismic excitation is investiagated with the Matlab/Simulink toolbox.

INTRODUCTION

Passive energy dissipation (PED) devices are a group of structural protective systems which are widely accepted by the engineering community. Passive control systems based on the structural response control are divided in two groups. The first group is used to reduce structural response by conversion of kinetic energy to heat and the second one by regarding the increased mass of oscillators, transfer energy among vibrational modes. The second group includes dynamic vibration absorber such as tuned mass damper (TMD), tuned liquid column damper (TLD) (Iemura et al., 2005).

Tuned mass dampers have supports that act as well as a spring and a damper themselves. Since the frequency of these dampers is tuned to natural frequency of the structure, these instruments are called tuned dampers (TD). This dampers moves under the lateral load of the structure and uses the inertial force (Conner, 2000; Soong and Dargush ,1997). For damper`s better function, it is deployed in upper floors of the building and the damper needs less mass, when is in top floor (Imani, H. 1387).The mass rests on bearing that function as rollers and allow the mass to translate between the mass and the adjacent vertical support members which transmit the lateral “out-of-phase” force to the floor level, and then into the structural frame (Conner, 2000; Soong and Dargush ,1997).

A Tuned liquid damper (TLD) consists of a tank partially filled with liquid (preferably water). The various mechanisms of the energy dissipation are viscous action of the fluid, wave breaking, and contamination of the free surface with beads and container geometry and roughness (Yalla, 2001).

The TLDs can be broadly classified into two categories: shallow-water and deep-water dampers. This classification is based on the ratio of the water depth to the length of the tank in the direction of the motion. A ratio of less than 0.15 is representative of the shallow water case. The deep-water damper has one drawback in the fact that a large portion of water does not participate in sloshing and adds to the dead weight (Yalla, 2001).

In this paper, the effect of TLD and TMD in seismic applications is presented and compared on a 22-DOF building with the Matlab/Simulink toolbox. Tuned dampers are designed by using the optimal formulas.

FORMULATION

Equation of Structure and Dampers

The equation of motion of MDOF systems under seismic excitation is:

$$M\ddot{u} + C\dot{u} + Ku = -M\ddot{x}_g \tag{1}$$

Where $\ddot{u}, \dot{u}, u$ are the acceleration, velocity, displacement of the structure respectively. M, C, D are the Mass, damping and stiffness of MDOF and $\ddot{x}_g$ is the acceleration of ground motion

According to the same performance of TLD and TMD, the equation of motion of a multi-degree structure equipped by tuned dampers is as follows (Chang and Qu, 1998; Hochrainer and Ziegler, 2006):

$$(1 + \mu_2)\ddot{x} + \mu_3\ddot{x}_d + 2\xi_s\omega_s\dot{x} + \omega_s^2 x = -L_j\ddot{x}_g \tag{2}$$

The equation of motion of dampers under seismic loads is (Chang and Qu, 1998; Hochrainer and Ziegler, 2006):

$$\mu_3\ddot{x} + \mu_1\ddot{x}_d + 2\mu_1\xi_d\omega_d\dot{x}_d + \mu_1\omega_d^2 x_d = -\mu_1\ddot{x}_g \tag{3}$$

Where ξ_s, ω_s are the damping and frequency of the structure and $\ddot{x}, \dot{x}, x$ is the acceleration, velocity, displacement of the floor, respectively. $\ddot{x}_d, \dot{x}_d, x_d, \xi_d$ و ω_d is the acceleration, velocity, displacement, damping and frequency of the damper, respectively.

$$L_j = \frac{\vec{\phi_j}^T . M_s . \vec{1} + \phi_{jk} . m_d}{\vec{\phi_j}^T . M_s . \vec{\phi_j}} \tag{4}$$

ϕ_j is mode shape of the j mode and ϕ_{jk} is the j mode shape value at the location where the dynamic absorber is installed.

For the case of TMD, these coefficients can be expressed as:

$$\mu_1 = \mu; \qquad \mu_2 = \phi_{jk}^2 . \mu \; ; \qquad \mu_3 = \phi_{jk} . \mu \qquad \text{(5a, b, c)} \tag{5}$$

For the case of TLD, these coefficients can be expressed as follows:

$$\mu_1 = \frac{8}{\pi^3}\frac{L}{h}\tanh\left(\frac{\pi h}{L}\right) . \mu; \qquad \mu_2 = \phi_{jk}^2 . \mu \; ; \qquad \mu_3 = \phi_{jk} . \mu_1 \qquad \text{(6a, b, c)} \tag{6}$$

And for both dampers:

$$\mu = \frac{m_d}{\vec{\phi_j}^T . M_s . \vec{\phi_j}} \tag{7}$$

The Optimal Formulas

In tuned dampers, mass ratio (μ) has a great influence on reducing structural response. weight of a moving mass is between 0.1 to 2.5 percent of the weight of the building and is usually located in upper floors of the buildings (Soong and Dargush ,1997). Dampers opration is improved as mass ratio is increased. It is impossible to install the damper on top floor with mass ratio more than 2 percent beacuase it occupies large space. In this study mass ratio is assumed 2 percent.

Experimental and numerical studies indicate that tuned dampers are sensitive to the tuning frequency. Conner (2000) optimized tuning frequency for TMD and present following equation:

$$\alpha_{opt} = \frac{\omega_d}{\omega_s} = \frac{1}{1+\mu} \tag{8}$$

It should be that frequency of TLD is depend on height of liquid (h) and the length of the tank in the excitation direction (L). It can be expressed as (Kim et.al 2006; Chang and Qu, 1998):

$$\omega_d = \sqrt{\frac{\pi g}{L}\tanh\left(\frac{\pi h}{L}\right)} \tag{9}$$

To optimize damping of TDs is necessary for their performance investigations. Many researches on optimized damping are done. Chang and Qu (1998) optimized damping of TMDs considered mass ratio as:

$$\xi_{dopt} = \sqrt{(3\mu/8(1+\mu))} \tag{10}$$

Chang and Gu (1999) have optimized design damping of TLDs.

$$\xi_{dopt} = \left|\frac{\sqrt{1+\mu_2}-\sqrt{1+\mu_2+\mu_3}}{2\sqrt{1+\mu_2}}\right|^{1/2} \tag{11}$$

In this study is used shallow-water TLD because in the deep-water damper a large portion of water does not participate in sloshing and adds to the dead weight.

LOAD CASES

In order to investigate the performance of dampers under earthquake excitations, in the current study, four earthquake acceleration records, which cover the wide frequency band, were used as input ground motion. Peak ground acceleration (PGA) has scaled to 0.3g, 0.5g and 0.8g as low, moderate and extreme levels (Fig 1). Fourier specteral shows in Fig 2.

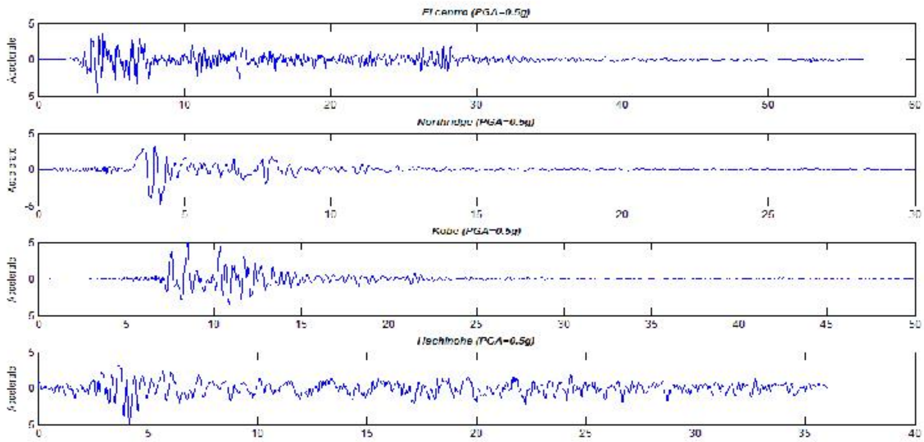

Figure 1. Seismic Loads

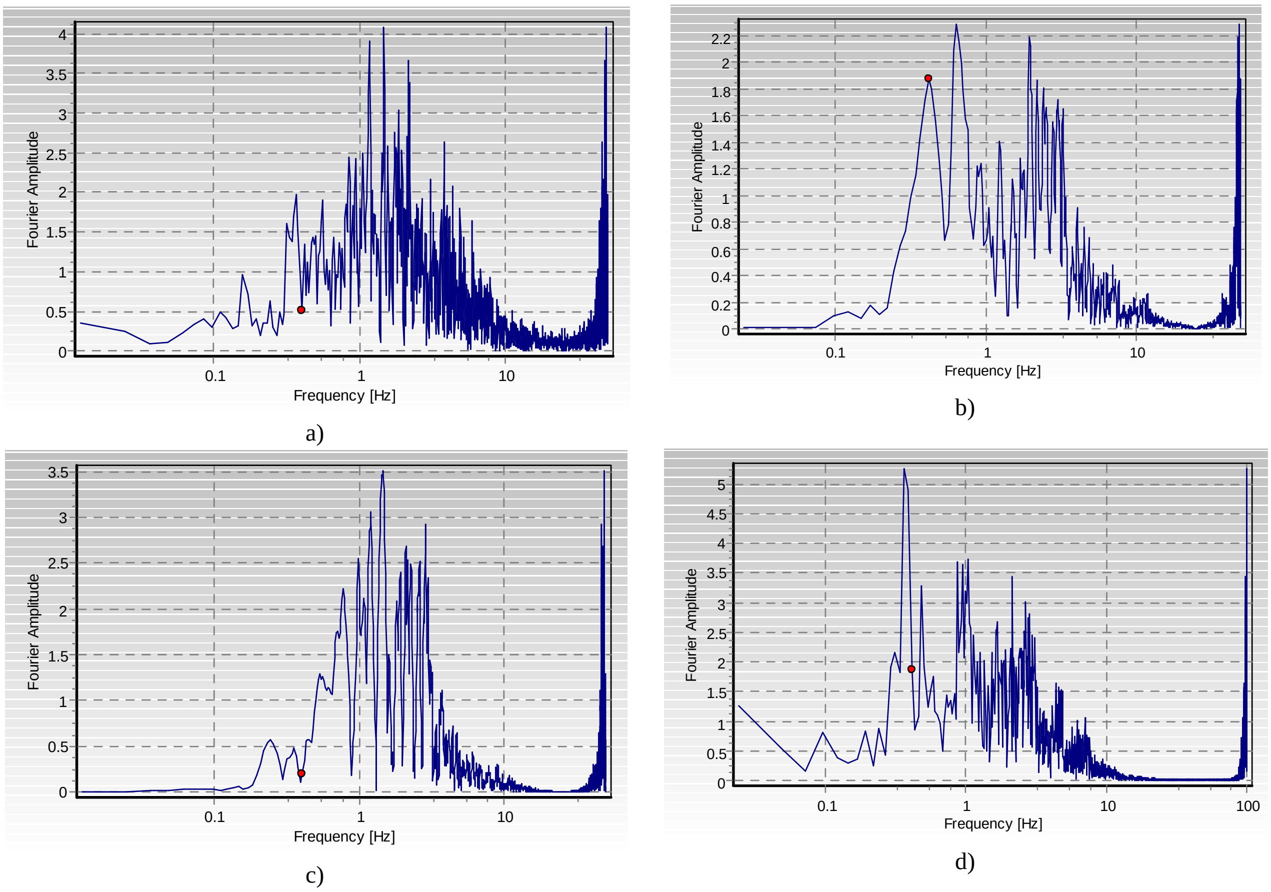

Figure 2. Fourier specturam a)Elcentro, b)Northridge, c)Kobe, d)Hachinohe

CASE STUDY

The 22 floors building of C6 located in the town ShahidBagheri with 77.85 (m) height has been investigated with the Matlab/Simulink toolbox. Its natural frequencyand modal mass is 0.4 (Hz) and 1190 (ton), respectively (Fig 3).

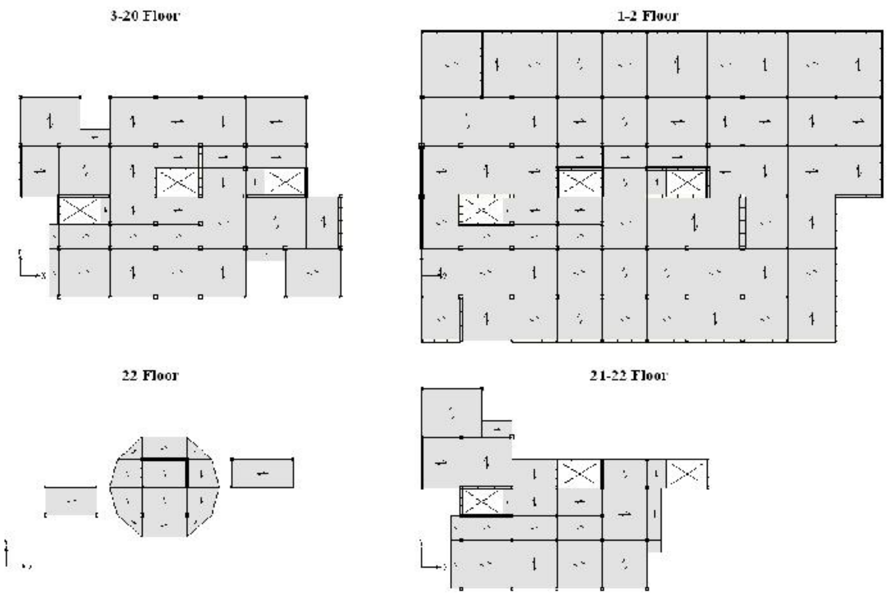

Figure 3. PLAN of Shahid Bagheri building

5. RESULT AND DISCUSSION

RMS of displacement, PI_RMS and PI displacement were used to compare the performance of dampers.

$$RMS = \sqrt{\frac{\sum_{i=1}^{n} x^2}{n}} \tag{12}$$

$$PI\_RMS = 1 - \left(\frac{RMS_{controlled}}{RMS_{uncontrolled}}\right) \tag{13}$$

$$PI\_disp = 1 - \left(\frac{max(x_{controlled})}{max(x_{uncontrolled})}\right) \tag{14}$$

Structural responses under seismic excitation are shown in Fig 4.

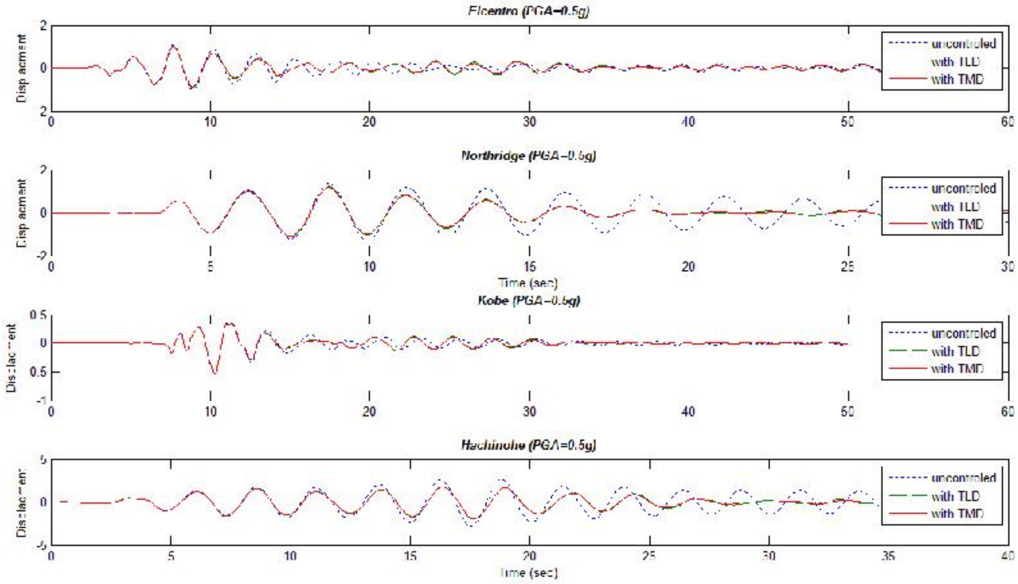

Figure 4. Response of uncontrolled structure and structure with TLD and TMD

Table 1 shows the result of damper performance under different earthquake excitations.

Table1. Percent reduction Response (PGA=0.3g,0.5g,0.8g)

		Elcentro	Hachinohe	Kobe	Northridge
TLD	PI_RMS	12	34	6	34
	PI_displacement	6	30	1	12
TMD	PI_RMS	16	37	8	37
	PI_displacement	7	32	1	14

CONCLUSIONS

The response of the 22-DOF building with TLD and TMD under seismic excitation is studied. By comparing the results in accelerations PGA=0.3g, 0.5g and 0.8g, it is clear that if the optimal tuned dampers were designed, the dampers' effectiveness did not change as PGA increases. Tuned dampers have better performance for reduction of PI_RMS than reduction of maximum displacment (PI_displacment). Comparison between TMD and TLD showed that TMD is more effective for reducing the maximum displacement and RMS of selected structure than TLD.

Unlike the Kobe record, the Hachinohe record is repeated harmonically. Thus, the dampers have the best performance in Hachinohe.

According to Northridge Fourier specturam, 0.4 Hz frequency, equal to strucure frequency, is one of the maximum of Northridge earthquake frequency content, while there isn't the maximum frequency close to structure frequency in other record fourier spectrums. Proportional to obtain results in table 1, tuned dampers considerbly reduce structure response in Northridge rather than Kobe and Elcentro seismic, therefore it seems that the tuned damper performance is increased in resonance.

More accurate judgment require recognition of frequency content changes at any moment, that will be done in future.

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