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MULTIPLE TUNED MASS DAMPERS FOR SEISMIC-EXCITED TALL BUILDING

YOUNG-MOON KIM[1], KI-PYO YOU[1], JANG-YOUL YOU[2], SUN-YOUNG PAEK[3], BYUNG-HEE NAM[3], and DOO-KIE KIM[4]

[1]*Dept of Architecture Engineering Chonbuk National University, Jeonju, Korea, Long-Span steel Frame system Research Center*
[2] *Dept of Architecture Engineering Songwon University, Gwangju, Korea*
[3]*Dept of Architecture Engineering Chonbuk National University, Jeonju, Korea*
[4]*Dept of Civil and Environmental Engineering, Kunsan National University, Kunsan, Korea*

Multiple tuned mass dampers (MTMD) is used for suppressing seismic excitation of tall building. The performance of MTMD is compared with that of a single tuned mass system (TMD). Optimum parameters of TMD/MTMD for minimizing the variance response of the damped primary structure derived by Krenk, Igusa, and Jangid were used. The optimally designed MTMD system is more effective than that of a single TMD system for reducing seismic excitation of a tall building.

Keywords: MTMD, Tuned mass system, Tall structures.

1 INTRODUCTION

Tuned Mass Damper (TMD) is a classical vibration control device consisting of a mass, a spring and a damper supported at the primary vibrating structure (Patil 2011). The optimum tuning frequency and damping ratio for the undamped primary structure under harmonic and white noise random excitations was derived by Den Hartog, Warburton and Ayroinde (Den Hartog 1985, Ayroinde 1980). Krenk derived the optimum parameters of TMD for the damped primary structure (Krenk 2008). And MTMD having distributed natural frequencies around the natural frequency of system has been utilized (Xu 1992, Patil 2011). Xu & Igusa carried out parametric studies of closely spaced natural frequencies of MTMD under a wide-band random excitation (Xu 1992).

In this study, the performance of MTMD for suppressing seismic-excitation of a tall building under the El-Centro 1940 N-S component earthquake ground motion is investigated.

2 EQUATIONS OF MOTION

Dynamic analysis procedure can be simplified if the contribution of higher modes of the primary structure is ignored (Kareem 1995). Therefore, tall building-MTMD system can be modeled as the first- mode generalized SDOF/MTMD system as shown in Figure 1.

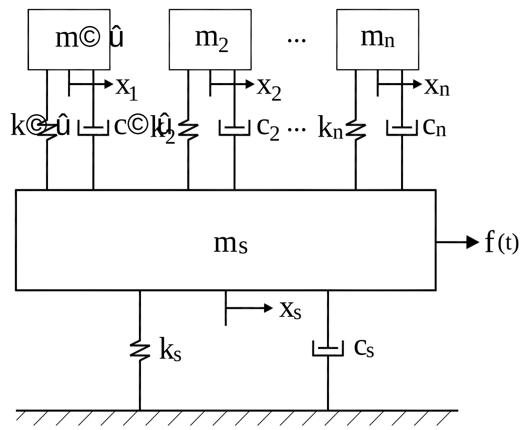

Figure 1. Tall building-MTMD model.

Dynamic equations of motion of the system can be written in matrix form of Eq. (1):

$$M\ddot{X} + C\dot{X} + KX = f(t) \tag{1}$$

where

$$X = \begin{bmatrix} x_s & x_1 & x_2 & \cdot\cdot & x_n \end{bmatrix} \tag{2}$$

$$M = \begin{bmatrix} m_s & 0 & 0 & 0 & \cdot & 0 \\ 0 & m_1 & 0 & 0 & \cdot & 0 \\ 0 & 0 & m_2 & 0 & \cdot & 0 \\ 0 & 0 & 0 & m_3 & \cdot & 0 \\ \cdot & \cdot & \cdot & \cdot & \cdot & 0 \\ 0 & 0 & 0 & 0 & 0 & m_n \end{bmatrix} \tag{3}$$

$$C = \begin{bmatrix} C_s + \sum_{j=1}^{n} c_j & -c_1 & -c_2 & -c_3 & \cdot & -c_n \\ -c_1 & c_1 & 0 & 0 & \cdot & 0 \\ -c_2 & 0 & c_2 & 0 & \cdot & 0 \\ -c_3 & 0 & 0 & c_3 & \cdot & 0 \\ \cdot & \cdot & \cdot & \cdot & \cdot & 0 \\ -c_n & 0 & 0 & 0 & 0 & c_n \end{bmatrix} \tag{4}$$

$$K = \begin{bmatrix} K_s + \sum_{j=1}^{n} k_j & -k_1 & -k_2 & -k_3 & \cdot & -k_n \\ -k_1 & k_1 & 0 & 0 & \cdot & 0 \\ -k_2 & 0 & k_2 & 0 & \cdot & 0 \\ -k_3 & 0 & 0 & k_3 & \cdot & 0 \\ \cdot & \cdot & \cdot & \cdot & \cdot & 0 \\ -k_n & 0 & 0 & 0 & 0 & k_n \end{bmatrix} \tag{5}$$

Where M, C, K = the mass, damping and stiffness matrix of tall building with MTMD, *f(t)* = ground acceleration; m_s $c_{s,}$ $k_{s,=}$ the first-mode modal mass, damping and stiffness constant of tall building, m_i $c_{i,}$ $k_{i,=}$ the mass, damping and stiffness constant of each TMD of MTMD:

x_s , $\dot{x}_s$, $\ddot{x}_{s}$ = displacement, velocity and acceleration response of a tall building; x_j , $\dot{x}_j$, $\ddot{x}_j$ = displacement, velocity and acceleration response of TMD,

Dynamic equations of motion of the system can be rewritten as a state-space formulation as

$$\dot{Z} = AZ + Hf(t) \tag{6}$$

where

$$Z = \begin{bmatrix} x & x_1 & x_2 & \cdots & x_n & , & \dot{x} & \dot{x}_1 & \dot{x}_2 & \cdots & \dot{x}_n \end{bmatrix} \tag{7}$$

$$A = \begin{bmatrix} 0 & I \\ -M^{-1}k & -M^{-1}C \end{bmatrix} \tag{8}$$

$$H = \begin{bmatrix} 0 & M^{-1} \end{bmatrix}^T \tag{9}$$

Z = state vector of primary structure with MTMD system; *A* = system matrix; *H* = the location vector of *f(t)*.

3 OPTIMUM PARAMETERS OF TMD

Krenk derived the optimum parameters of TMD for the damped primary structure (Krenk 2008).

$$f_{opt} = \frac{1}{1+\mu} \tag{10}$$

$$\xi_{opt} = \frac{\sqrt{\mu}}{2} \tag{11}$$

where f_{opt}= optimum tuning frequency; ξ_{opt}= optimum damping ratio; and μ=mass ratio.

4 OPTIMUM PARAMETERS OF MTMD

4.1 Optimal Number of MTMD

Patil & Jangid proposed the optimal number of MTMD is 5. Therefore 5 MTMD are used in this study and the sum of all MTMD's masses is the same as the mass of a single TMD (Patil 2011).

4.2 Optimal Frequency Band Width

The natural frequencies of MTMD are distributed uniformly around their average natural frequency which is the same value of the fundamental natural frequency of the primary structure (Xu 1992).

The natural frequency of the *j*th TMD ω_j is expressed as

$$\omega_j = \omega_T \left[1 + \left(j - \frac{n+1}{2} \right) \frac{\omega_s}{n-1} \right] \tag{12}$$

where $\omega_T = \sum_{j=1}^{n} \omega_j / n$ is the average natural frequency of all MTMD; $\omega_s = \dfrac{\omega_n - \omega_1}{\omega_T}$ is the non-dimensional frequency spacing of the MTMD; ω_j =the natural frequency of *j*th TMD; and n = the total number of MTMD. The ratio of the total MTMD's mass to the primary structure's mass is defined as the mass ratio μ ;

$$\mu = \frac{\sum_{j=1}^{n} m_j}{m_s} = \frac{m_t}{m_s} \tag{13}$$

where m_t=total mass of MTMD; m_s=mass of the primary structure; and m_j = mass of the *j*th TMD. Patil & Jangid proposed the optimal frequency band width is 0.3 when the number of MTMD is 5 and the mass ratio is 1.0% (Patil 2011).

4.3 Optimal Tuning Frequency Ratio

Optimal tuning frequency ratio of MTMD is similar to a single TMD's, which is in Eq. (10) as *1/1+*μ. Patil & Jangid proposed that optimal tuning frequency ratio is 1.0 when the number of MTMD is 5 and the mass ratio is 1.0% (Patil 2011).

4.4 Optimal Damping Ratio

If each TMD of MTMD has the same stiffness and damping constant for easy manufacturing MTMD, the stiffness constant k_T and damping constant c_T of each TMD can be evaluated as

$$k_T = \mu m_s / \left(\sum_{j=1}^{n} \frac{1}{\omega_j^{\,2}} \right) \tag{14}$$

$$c_T = 2 k_T \zeta_T / \omega_T \tag{15}$$

where ξ_T = average damping ratio of the MTMD expressed as

$$\xi_T = \sum_{j=1}^{n} \frac{\xi_j}{n} = \frac{\omega_T c_T}{2 k_T} \tag{16}$$

where ξ_j = damping ratio of the *j*th TMD. The mass of the *j*th TMD are expressed as

$$m_j = k_T / \omega_j^{\,2} \tag{17}$$

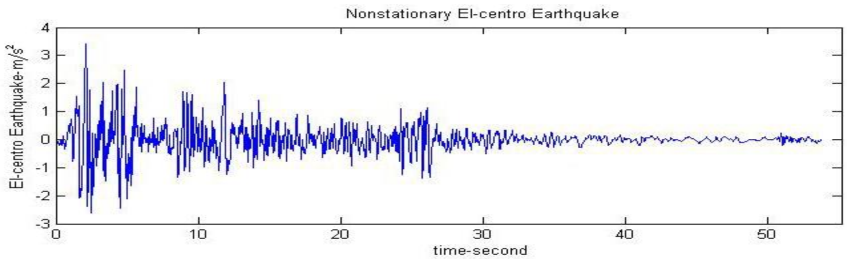

Figure 2. Accelerogram of El-Centro 1940 N-S component earthquake ground motion.

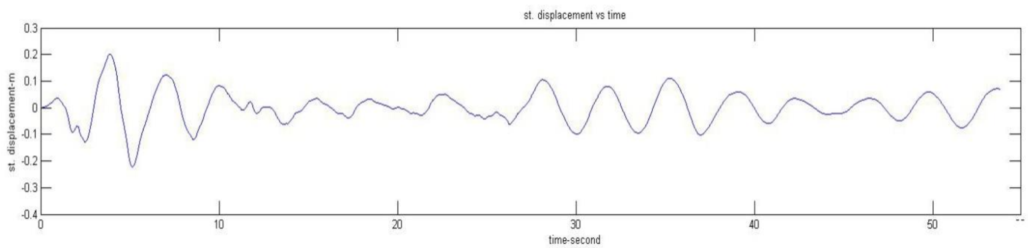

Figure 3. Dynamic Responses without TMD (rms=0.0595m).

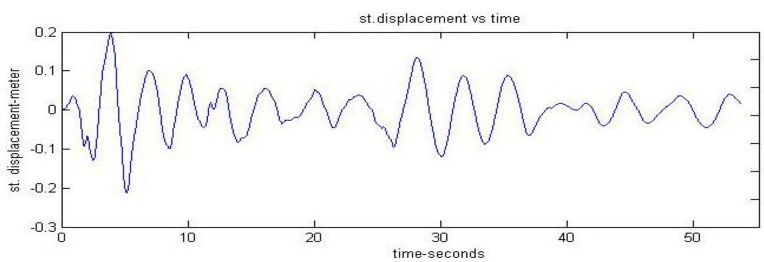

Figure 4. Dynamic Responses with TMD (rms=0.0586m).

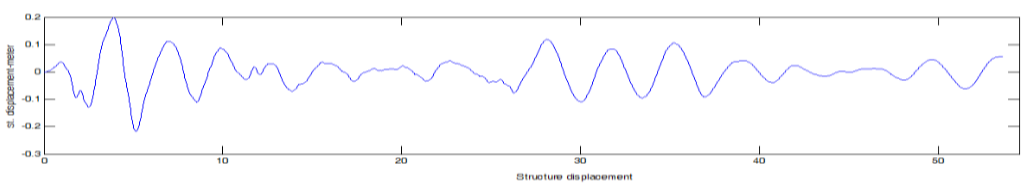

Figure 5. Dynamic Responses with MTMD (rms=0.0573m).

5 NUMERICAL EXAMPLE

This numerical example is from "Numerical Examples" in reference (Solari 1993). The tall building's height H = 180m, width B = 60m, depth D = 30m. The modal mass, damping and stiffness constants are $2.4*10^7 k_g$, $1.220832*10^6$ N-s/m, and $6.9001425*10^7$ N/m. Natural frequency f_1 = 0.27Hz, damping r$_a$tio ξ_1 = 0.015. The optimum parameters of MTMD were used. Figure 2 shows the actual accelerogram of El-Centro 1940 N-S component earthquake ground motion. Dynamic rms response of tall building without TMD is 0.0595m, shown in Figure 3. And dynamic rms response with a single TMD is 0.0586m shown in Figure 4, which shows the reduction effect is about 2%. Dynamic rms response of a tall building with MTMD is 0.0573m, shown in Figure 5, which shows that 4% reduction effect could be obtained.

6 CONCLUSIONS

The performance of MTMD and a single TMD for suppressing seismic excitation of tall building is investigated. Optimum parameters of MTMD for minimizing the variance response of the damped main structure were used. Suppressed rms response with MTMD is smaller than that of a single TMD. However, that effectiveness is not significant as known before.

Acknowledgment

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