Frequency-response functions on uniform building with seismic response active control using the hybrid system

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ABSTRACT: This paper is performed to evaluate vibration characteristics of buildings with seismic response control using active mass damper (AMD) and/or tuned mass damper (TMD). Especially, it is employed ordinary story building with seismic base isolation. The fundamental natural frequency on this system is 0.5 Hz. Frequency-response functions on uniform building with seismic base isolation that is set AMD and/or TMD have been derived as general solutions of difference equations. Employing simple expressions of frequency-response functions on acceleration and displacement responses, seismic response control mechanisms depend mainly upon mounting mass quantity, frequency, or setting story of AMD and/or TMD. Seismic responses of these buildings are evaluated by frequency-response functions and Fourier transform process. Then, the effectiveness of seismic response control using AMD and/or TMD is also studied.

1 INTRODUCTION

Many studies and practical uses of structures with seismic response control systems are recently performed. The seismic response control technology enables structures to make drastic reduction of acceleration and displacement responses. From a point of view, this study is performed to evaluate vibration characteristics of buildings with seismic response control using active mass damper (AMD) and/or tuned mass damper (TMD). In this analysis, it is employed ordinary story building with seismic base isolation. For base isolated building, in general, very large relative displacement to the ground may be occur. Then, seismic response control effects using AMD and/or TMD are examined. Parameters for the analysis are mass quantity, stiffness, valid control power, combination and set story of mass damper.

It is assumed the model of base isolated uniform building with seismic response control using AMD and/or TMD. AMD and/or TMD is laid out on the optional story of this building, shown in Fig. 1. Frequency-response functions of such a system are derived as general solutions of difference equations. Employing simple expressions of frequency-response functions on acceleration and displacement responses, seismic response control mechanisms of AMD and/or TMD are investigated. Seismic responses of these buildings are also evaluated by frequency-response functions and Fourier transform process.

Fig. 1 The Analytical Model & Co-ordinates
2 FORMULATION OF FREQUENCY-RESPONSE FUNCTIONS

A general solution of frequency-response functions for this analysis is described in the case where base isolated uniform building has seismic response control using AMD and TMD at the top of this building. As the input excitations into such a system, they may be ground motions that are steady state sinusoidal waves. The excitation history of the ground motion is \( y(t) = e^{i\omega t} \), where \( \omega \) is circular frequency of input sinusoidal wave, and the response histories of the system are \( \ddot{x}_j(t) = H_{ij}e^{i\omega t} (j = n-\infty) \). \( H_{ij}e^{i\omega t} \) is the frequency-response function as to acceleration at \( j \)-th story. The following three-term equations for frequency-response functions are obtained by substituting these functions in the equations of motion.

\[
\begin{align*}
(\omega^2 - b) \dddot{x}_1 + b \dot{x}_1 + \ddot{x}_a &= 0 \\
(\omega^2 - a) \dddot{x}_a + a \dot{x}_a &= p \\
\epsilon \dddot{x}_a + \epsilon \dddot{x}_1 + (\omega^2 - 2\epsilon) \dddot{x}_a + \epsilon \dddot{x}_{a-1} &= q \\
\epsilon \dddot{x}_a + (\omega^2 - 2\epsilon) \dddot{x}_1 + \epsilon \dddot{x}_{a-1} &= 0 \\
\epsilon \dddot{x}_1 + (\omega^2 - 2\epsilon) \dddot{x}_a &= -g \\
f \dddot{x}_a + (\omega^2 - 2\epsilon) \dddot{x}_a &= 0
\end{align*}
\]

Therefore, the general solutions are

\[
[TMD] \quad H_{x_1} = \frac{-b(C_1\beta^{-n-1} + C_2)}{\omega^2 - b}
\]

\[
[AMD] \quad H_{x_a} = \left(p - a(C_1\beta^{-n-1} + C_2)\right) / \omega^2 - a
\]

\[
[n-1] \quad H_{x_{j-1}} = C_1\beta^{-j-1} + C_2\beta^{-(j-n-1)}
\]

\[
[Base] \quad H_{x_0} = \frac{1 - f(C_1 + C_2\beta^{n+1})}{\omega^2 - g}
\]

where

\[
\beta = \frac{-(\omega^2 - c) \pm \sqrt{(\omega^4 - 4c\omega^2)}}{2c}
\]

\( C_1 \) and \( C_2 \), integral constants, are determined by using boundary conditions. \( a, b, c, d, e, f, g, p, q \) are functions of \( \omega \) and \( \beta \).

The frequency-response functions as to relative displacement are also obtained by the same method described before.

4 FREQUENCY-RESPONSE FUNCTIONS

Acceleration frequency-response functions at the top(7-th story) of the building are shown in Fig. 3. Each curves denote some parametric variables. Peaks at the fundamental frequency are sensitive to their parametric variables. Any cases have narrower band peaks at the fundamental frequency. Peaks at the second frequency are not appear.

Displacement frequency-response functions at the base isolation are shown in Fig. 4. Any cases have narrower band peaks at the fundamental frequency in the same as acceleration frequency-response functions. Peaks at the second frequency cannot be seen.
5 SEISMIC RESPONSES

El Centro NS (1940) and Hachinohe NS (1968) normalized to be 50 kine at maximum velocity are employed as input excitations of earthquake. Time histories of the response are shown in Fig. 5 (acceleration at the top of the superstructure) and Fig. 6 (displacement at the base isolation). Maxima of responses of acceleration at each story and displacement at the base isolation are listed in Tab. 1. They have been selected reasonable, effective, and economical parameters. Mass damper has 1% total weight of the system. They show that AMD using Feed-back control theory is the most effective of all.

6 CONCLUSION

The base isolated buildings with seismic response control using AMD and/or TMD are analytically studied. It is shown that

1) Frequency-response functions of such a system are derived as general solutions of difference equations.

2) Frequency-response characteristics depend mainly upon mass quantity, frequency, combination and set story of mass damper.

3) The system with AMD using Feed-back control theory is the most effective of all models, and the remarkable reductions of seismic responses are obtained.

Fig. 3 Acceleration Frequency-response Functions

Fig. 4 Displacement Frequency-response Functions
REFERENCES


![Graphs showing time histories of acceleration and displacement response](image)

**Fig. 5** Time Histories of the Acceleration Response at the Top (El Centro NS)

![Graphs showing time histories of displacement response](image)

**Fig. 6** Time Histories of the Displacement Response at the Base (El Centro NS)

### Tab. 1 a) Maxima of Responses (El Centro NS)

<table>
<thead>
<tr>
<th>Response</th>
<th>Story</th>
<th>Non-damping</th>
<th>Viscous damper</th>
<th>TMD</th>
<th>AMD-1</th>
<th>AMD-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>0.83</td>
<td>0.61</td>
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<td>0.45</td>
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<tr>
<td>2nd</td>
<td>0.82</td>
<td>0.53</td>
<td>0.65</td>
<td>0.99</td>
<td>0.44</td>
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<tr>
<td>3rd</td>
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<td>0.64</td>
<td>0.70</td>
<td>0.45</td>
<td></td>
</tr>
<tr>
<td>4th</td>
<td>0.81</td>
<td>0.50</td>
<td>0.62</td>
<td>0.60</td>
<td>0.33</td>
<td></td>
</tr>
<tr>
<td>5th</td>
<td>0.81</td>
<td>0.51</td>
<td>0.63</td>
<td>0.60</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>Magnification</td>
<td>0.81</td>
<td>0.50</td>
<td>0.62</td>
<td>0.80</td>
<td>0.63</td>
<td>0.45</td>
</tr>
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<td>1st base</td>
<td>0.79</td>
<td>0.49</td>
<td>0.50</td>
<td>0.81</td>
<td>0.66</td>
<td>0.42</td>
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*1: Feed Forward Control 2: Feed Back Control

### Tab. 1 b) Maxima of Responses (Hachinohe NS)

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<th>TMD</th>
<th>AMD-1</th>
<th>AMD-2</th>
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<td>Magnification</td>
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<tr>
<td>1st base</td>
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<td>0.99</td>
<td>1.10</td>
<td>0.87</td>
<td>0.51</td>
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</table>

*1: Feed Forward Control 2: Feed Back Control

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