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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 turned 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. Frequnecy-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 frequnecy-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 accelaretion 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 turned 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. Frequnecy-response functions of such a system are derived as general solutions of difference equations. Employing simple expressions of frequnecy-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.

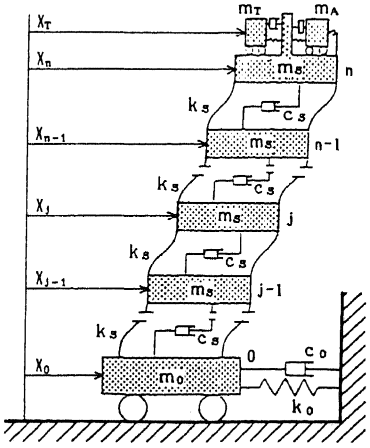

Fig. 1 The Analytical Model & Co-ordinates

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 $\ddot{y}(t)=e^{i\omega t}$, where ω is circular frequency of input sinusoidal wave, and the response histories of the system are $\ddot{X}_j(t) = H\ddot{x}_j e^{i\omega t}\ (j=n\sim 0)$. $H\ddot{x}_j e^{i\omega t}$ 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.

$$\left[\begin{array}{rrrl}
 & & (\omega^2-b)H\ddot{x}_T & +bH\ddot{x}_n =0\\
 & & (\omega^2-a)H\ddot{x}_A & +aH\ddot{x}_n =p\\
cH\ddot{x}_A+dH\ddot{x}_T+ & & (\omega^2-c-d-e)H\ddot{x}_n & +eH\ddot{x}_{n-1}=q\\
 & eH\ddot{x}_n+ & (\omega^2-2e)H\ddot{x}_{n-1} & +eH\ddot{x}_{n-2}=0\\
 & - - - - & - - - - - - & - - - - - -\\
 & eH\ddot{x}_2+ & (\omega^2-2e)H\ddot{x}_1 & +eH\ddot{x}_B =0\\
 & fH\ddot{x}_1+ & (\omega^2-f-g)H\ddot{x}_B & =-g
\end{array}\right.$$

Therefore, the gerenal solutions are

$$[\mathrm{TMD}]\quad H\ddot{x}_T=-\frac{b(C_1\cdot\beta^{n-1}+C_2)}{\omega_2-b}$$

$$[\mathrm{AMD}]\quad H\ddot{x}_A=\frac{p-a(C_1\cdot\beta^{n-1}+C_2)}{\omega^2-a}$$

$$[n\sim 1]\quad H\ddot{x}_j=C_1\cdot\beta^{j-1}+C_2\cdot\beta^{-(j-n)}$$

$$[\mathrm{Base}]\quad H\ddot{x}_B=-\frac{1-f(C_1+C_2\cdot\beta^{n-1})}{\omega^2-g}$$

where

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

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 ω and β .

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

3 ANALITICAL MODELS

Based on a existing seven stories building, that has 4,100 tonf in total weight and prototype plane shown in Fig. 2, consisting of reinforced concrete frame with shear walls, it is assumed that the building is shear type. Then, the building is uniform as to lateral stiffness(1,300 tonf/cm) and lumped mass in each story. Therefore, the fundamental natural period is 0.57 sec. It is 2.08 sec. in the case isolated by employing laminated rubbers.

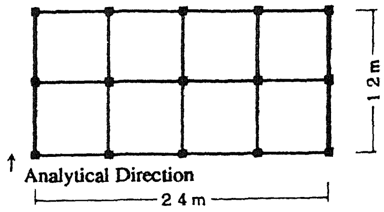

Fig. 2 Prototype Plane of Analytical Building

The kinds and the locations of the damper in this present study are following:

1) Case of non-damping system at any location.
2) With viscous damper at the base isolation.
3) With TMD at the top of the superstructure.
4) With AMD using Feed-forward control of relative isolation theory at the top of the superstructure.
5) Hybrid system with both TMD and above AMD at the top of the superstructure.
6) With AMD using Feed-back control theory at the top of the superstructure. As the control theory, Optimal Regulator Method is applied employing two Performance Indices. The performance index J_1 evaluates the mixed effects of the acceleration and the displacement as turn over method for large waiting Q. The another index J_2 is a simular effect.

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 the each story and displacement at the base isolation are listed up 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) Frequnecy-response functions of such a system are derived as general solutions of difference equations.

2) Frequnecy-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.

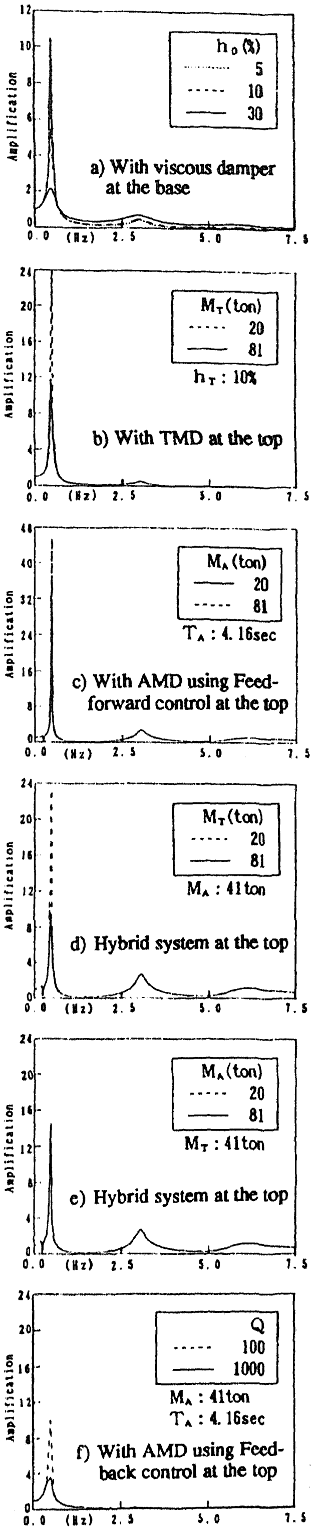

Fig. 3 Acceleration Frequency-response Functions

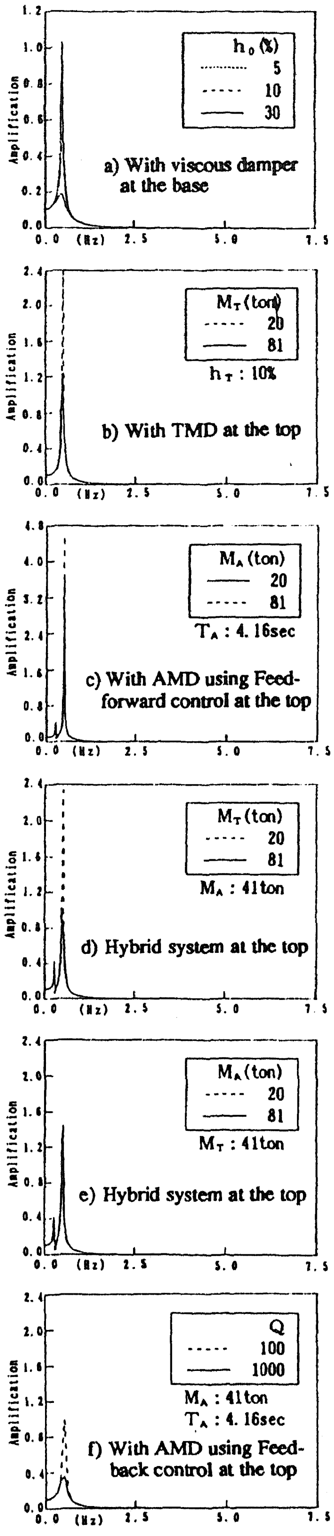

Fig. 4 Displacement Frequency-response Functions

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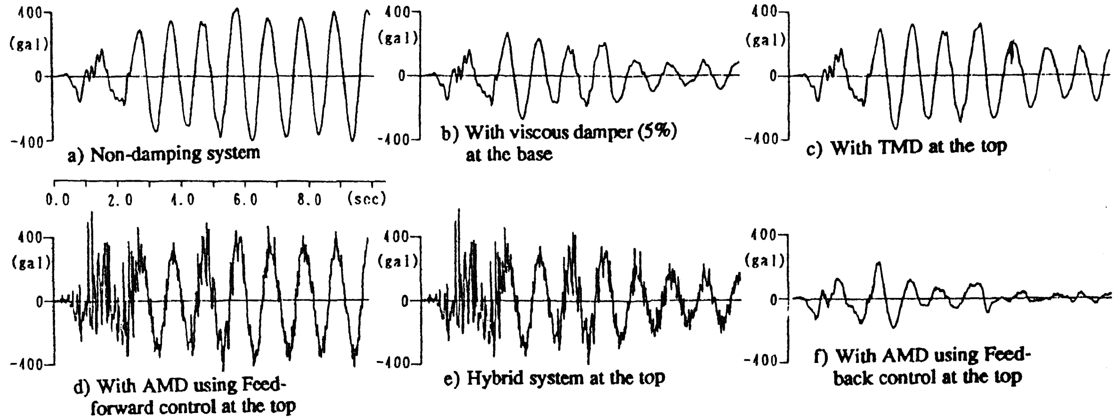
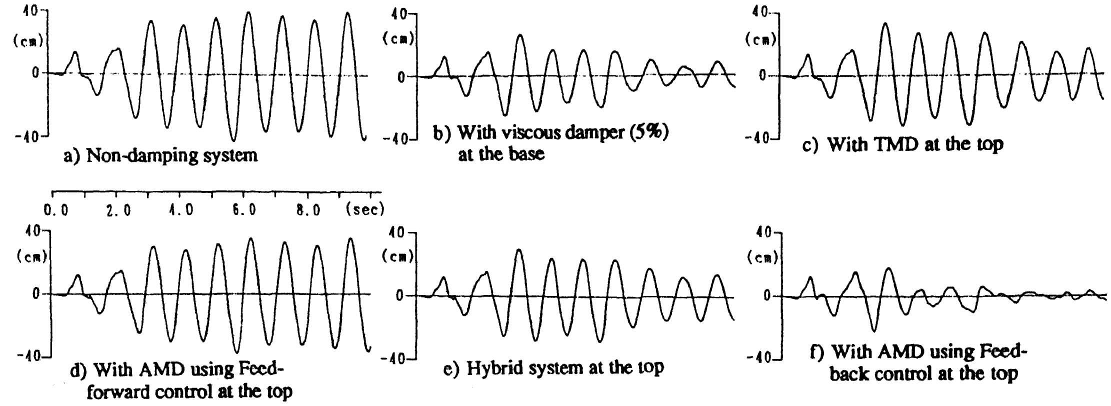


a) Non-damping system
b) With viscous damper (5%) at the base
c) With TMD at the top
d) With AMD using Feed-forward control at the top
e) Hybrid system at the top
f) With AMD using Feed-back control at the top

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



a) Non-damping system
b) With viscous damper (5%) at the base
c) With TMD at the top
d) With AMD using Feed-forward control at the top
e) Hybrid system at the top
f) With AMD using Feed-back control at the top

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

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

Response	story No.	Non-damper	Viscous Damper	TMD	AMD *1	TMD & AMD *1	AMD *2
Acceleration Magnification	7th	0.83	0.53	0.66	1.11	1.11	0.45
	6th	0.83	0.53	0.65	0.99	0.99	0.44
	5th	0.82	0.52	0.65	0.79	0.78	0.45
	4th	0.82	0.52	0.64	0.76	0.63	0.46
	3rd	0.81	0.51	0.63	0.80	0.63	0.46
	2nd	0.81	0.50	0.62	0.80	0.63	0.45
	1st	0.80	0.49	0.61	0.79	0.64	0.43
	base	0.79	0.48	0.60	0.81	0.66	0.42
Disp. (cm)	base	42.3	26.6	33.6	35.9	28.6	22.3

*1 : Feed Forward Control *2 : Feed Back Control

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

Response	story No.	Non-damper	Viscous Damper	TMD	AMD①	TMD & AMD①	AMD②
Acceleration Magnification	7th	1.42	0.82	1.07	1.32	1.09	0.54
	6th	1.41	0.81	1.06	1.29	0.99	0.54
	5th	1.40	0.81	1.05	1.26	0.95	0.54
	4th	1.38	0.80	1.04	1.21	0.90	0.53
	3rd	1.35	0.79	1.03	1.17	0.89	0.52
	2nd	1.32	0.78	1.01	1.12	0.88	0.51
	1st	1.29	0.77	0.98	1.10	0.87	0.51
	base	1.25	0.75	0.96	1.09	1.01	0.50
Disp. (cm)	base	45.7	26.6	34.7	38.8	29.3	18.1

*1 : Feed Forward Control *2 : Feed Back Control