Vibration Control of Asymmetric Building Subjected to Harmonic Excitation

Narayan B. Makwana[1], Snehal V. Mevada[2] and Vishal B. Patel[3]

[1]*PG Student, Structural Engineering Department, BVM Engineering College-VVNagar, Gujarat, India.*

[23] *Assistant Professor, Structural Engineering Department, BVMEngineering College-VVNagar, Gujarat, India.*

[3] *Assistant Professor, Structural Engineering Department, BVMEngineering College-VVNagar, Gujarat, India.*

Abstract

This paper includes the study ofbehavior of a single degree of freedom system withnon-linearviscous damper, semi active variable damper and semi active stiffness damper subjected to harmonic excitation. In this paper, single story asymmetric building is considered. The mathematical model of building subjected to harmonic excitation is obtained and solution of this is obtained by state space method. The building is considered with different dampers.The response of building is obtained under resonance and non-resonance condition and the comparison of response for these different cases is carried out.

Keywords—*Vibration control,Non Linear Viscous damper, Semi Active Variable Damper, Semi Active Stiffness Damper, Harmonic excitation, Resonance.*

I. INTRODUCTION

Various energy dissipating devices are used to reduce structural vibration, so that catastrophic structural failure can be prevented and it improves the human comfort. Energy dissipating devices can be used in medium to high rise structures. These energy dissipating devices can modify the response of the structure dynamically in acceptable limit so that these control system is also known as the protective system for the structures.

The energy which is imposed by natural disturbances should be dissipated in any way to reduce vibration of structures. Every structure naturally releases some energy by means of plastic deformation, internal stressing and rubbing. In addition to the inherent natural damping of structure, to increase the damping, various energy dissipatingdevices are used. These vibration control methods include four control systems which are listed as the(1) passive control system, (2) active control system, (3) semi-active control system and (4) hybrid control system.

In the past, some researchers have studied the harmonic response analysis of structures installed with various dampers. Liaoand Lai [1] investigated single degree of freedom isolation system with a Magneto-Rheological fluid damper under the harmonic excitations. It was concluded that the semi-active controlled Magneto-Rheological damper can reduce the vibration for various range of frequencies. The behavior of active mass damper and vibration control of the tall buildings under harmonic excitation is studied by Ricciardelli et al. [2]. It was observed that the parameters which was reduced have strong relation with the performance of devices.Eissa et al. [3] studied the vibration control using active control techniques. It was found out that the active control was effective for resonance case. Ervin and Wickert [4] studied the behavior of clamped-clamped beam attached with rigid body subjected to forced vibration with periodic or non-periodic impacts between body and base. The effect of structural asymmetry and eccentricity was studied. Scheller and Starossek [5] presented a versatile active mass damper which can be used for the control of structural vibrations of various excitation sources and observed that the rotor damper reduces the vibrations at low mass ratio.

Based on the brief literature review carried out herein, it is observed that less work has been reported to control the vibration of structures subjected to harmonic excitation using damper. This paper investigates the behavior of single storey asymmetric building subjected to harmonic excitation under resonance and non-resonance condition.The specific objective of the study is to obtain the parameters like lateral-torsional displacement and acceleration of the building withnon-linear viscous damper (NLVD), semi active variable damper (SAVD) and semi active stiffness damper (SASD) subjected to harmonic excitations.

II. EQUATIONS OF MOTION

The system considered is an idealized single storey asymmetric building which consists of rigid deck supported on column and the unbalanced rotating mass at the centre as shown in the figure 1 & 2.The plan of the asymmetric building is shown in the figure 1. The building is installed with the damper diagonally as shown in the figure 2. The configuration of the building is selected such that the stiffness asymmetry with respect to centre of mass in one direction produces and so that the centre of rigidity is located an eccentric distance e_x from the centre of mass. The system is symmetric in direction

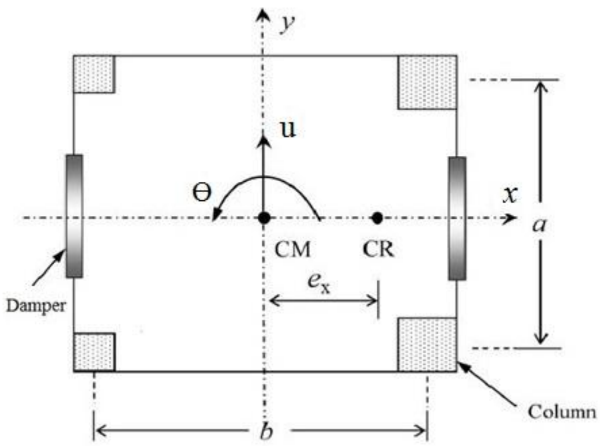

Figure 1: Plan of One Way Asymmetric Building

of '*x*' so that two degrees of freedom considered such as translational displacement in the direction of 'y', i.e. u and rotational displacement, Ɵas shown in the figure 1.

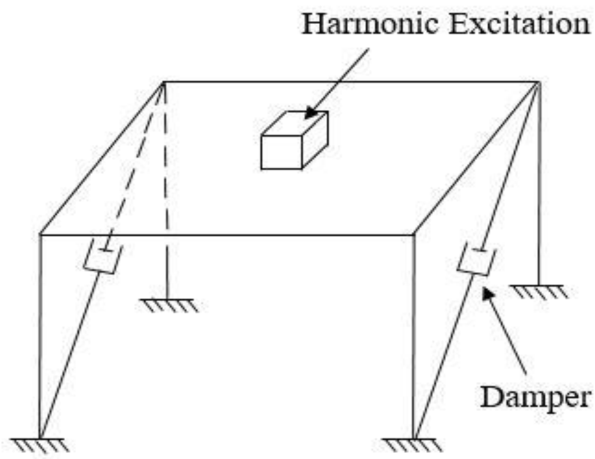

Figure 2: Arrangement of Damper in Building

Equation of motion for the considered building is as follows,

$$\boldsymbol{M\ddot{u}} + \boldsymbol{C\dot{u}} + \boldsymbol{Ku} = \Gamma \boldsymbol{F_h} + \wedge \boldsymbol{f} \qquad (1)$$

where, $\boldsymbol{M}$ = Mass matrix

$$= \begin{bmatrix} m & 0 \\ 0 & mr^2 \end{bmatrix},$$

$$r = \sqrt{\frac{a^2 + b^2}{12}}$$

$\boldsymbol{C}$= Damping matrix (5%)

$= a_0 M + a_1 K,$

$a_0 \& a_1$= coefficients depend on damping ratio of two vibration modes

$\boldsymbol{K}$ = Stiffness matrix,

$$= K_y \begin{bmatrix} 1 & e_x \\ e_x & e_x^2 + r^2\Omega_\theta^2 \end{bmatrix}$$

$$e_x = \frac{1}{K_y}\sum_i^n k y_i x_i,$$

$$\Omega_\theta = \frac{w_\theta}{w_y},$$

$$w_\theta = \sqrt{\frac{k_{\theta r}}{mr^2}},$$

$$w_y = \sqrt{\frac{k_y}{m}},$$

$$k_{\theta r} = k_{\theta\theta} - e_x^2 k_y,$$

$$k_{\theta\theta} = \sum_i^n k x_i y_i^2 + \sum_i^n k y_i x_i^2,$$

Solution of equation of motion is obtained using the State Space Method [6]:

$$\boldsymbol{z}[k+1] = \boldsymbol{A_d z}[k] + B_{\boldsymbol{d}} f[k] + E_d F_H \qquad (2)$$

$$\dot{\boldsymbol{z}} = Az + Bf + EF_H \qquad (3)$$

Where,$\boldsymbol{z}$ = State of Structure = $\begin{Bmatrix} \mathbf{u} \\ \dot{\boldsymbol{u}} \end{Bmatrix}$,

$$\dot{\boldsymbol{z}} = \begin{Bmatrix} \dot{\boldsymbol{u}} \\ \ddot{\boldsymbol{u}} \end{Bmatrix},$$

k = time step,

$\boldsymbol{A_d} = e^{\boldsymbol{A}\Delta t}$, represents the discrete-time system matrix with Δt as the time interval

$\boldsymbol{A}$ = System Matrix = $\begin{bmatrix} 0 & I \\ -M^{-1}K & -M^{-1}C \end{bmatrix}$,

$\boldsymbol{B}$= Distribution matrix of control forces = $\begin{bmatrix} \mathbf{0} \\ \boldsymbol{-M^{-1}} \wedge \end{bmatrix}$

E = Distribution matrix of excitations = -$\begin{bmatrix} \mathbf{0} \\ \Gamma \end{bmatrix}$

$$\boldsymbol{B_d} = A^{-1}(A_d - I)\text{B},$$

$$\boldsymbol{E_d} = A^{-1}(A_d - I)E,$$

III. NUMERICAL STUDY

The numerical study includes the behaviour of single storey asymmetric building installed with damper under harmonic excitation. The response of building like displacement and acceleration is obtained from the program developed in MATLAB.

Following are the properties of the flexible building subjected to harmonic excitation:

The mass and stiffness of building are adjusted such that time period of building comes out to be 0.70 seconds

Mass of motor to generate harmonic excitation = 500 kg

Radius of unbalanced rotating mass, r = 0.5 m,

Speed of motor, N = 268 rpm (for the resonance condition),

N = 380 rpm (for the non-resonance condition),

Forcing frequency, ω = 28.07 rad/s (for the resonance condition),

ω = 39.79 rad/s (for the non-resonance condition),

Excitation force, F = 10000 N.

Here the speed of the motor is selected that the frequency of motor matches with the natural frequency of building. The behavior of force with respect to time is shown in figure 3.

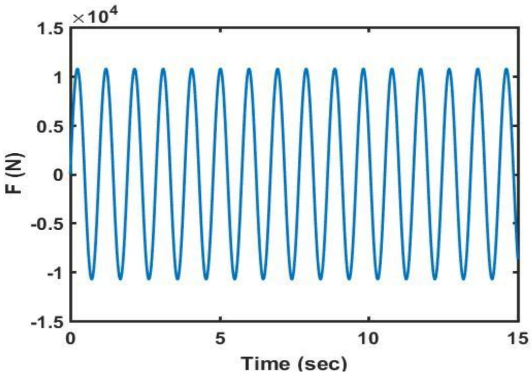

Figure 3: Variation of Applied Harmonic Force

The building is subjected to harmonic excitation and installed with damper such as non-linear viscous damper (NLVD), semi active variable damper (SAVD) and semi active stiffness damper (SASD). For this building two cases have been considered for the building Case (1) resonance condition (ω/ω_n = 0.99, Speed of motor = 268 rpm) and Case (2) non-resonance Condition ($\omega/\omega_n > \sqrt{2}$, Speed of motor = 380 rpm).

The results of the response of building like translational displacement, rotational displacement, translational acceleration and rotational acceleration are obtained and summerised in the table 1. The response of uncontrolled building and building installed with NLVD in resonance case is shown in the figure 4.

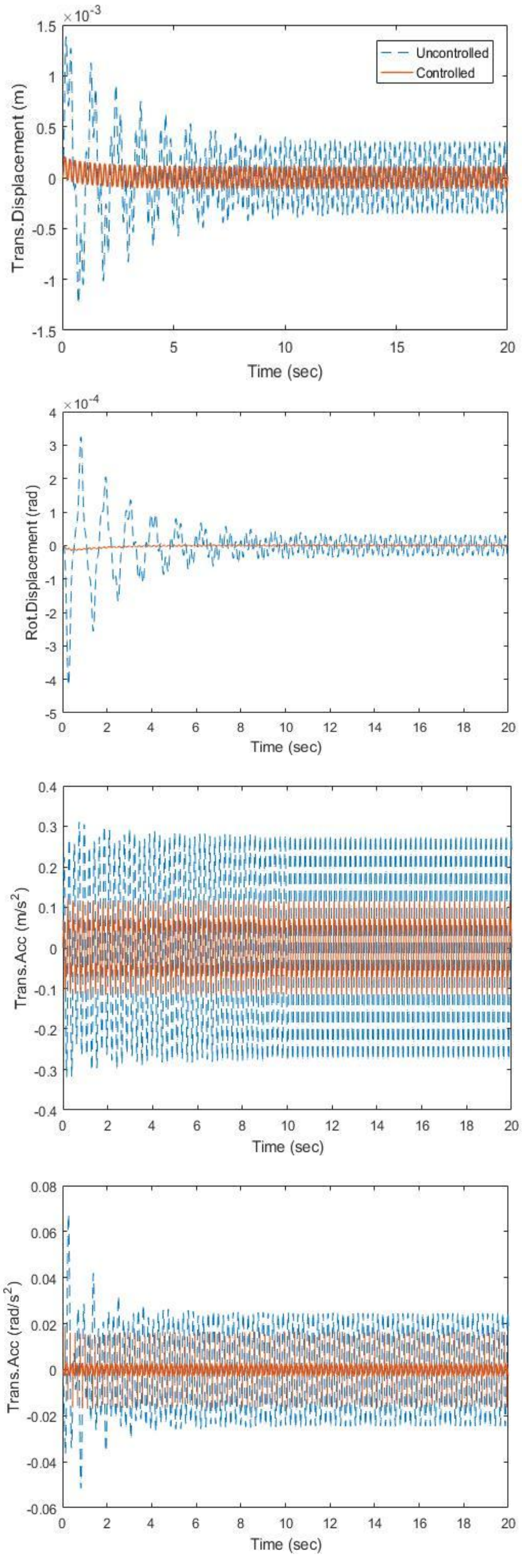

Figure 4: Response of Building (Resonance Case)

Table 1: Maximum Response Values of Building for Resonance and Non-Resonance Condition

Maximum Translational Displacement (m)				
Damper	**Resonance Case**		**Non-Resonance Case**	
	Uncontrolled	Controlled	Uncontrolled	Controlled
NLVD	0.0014	2.07×10^{-4} *(85.21 %)*	9.06×10^{-4}	1.38×10^{-4}*(84.77 %)*
SAVD		9.42×10^{-4} *(32.71 %)*		5.70×10^{-4}*(37.08 %)*
SASD		0.0011 *(21.43 %)*		6.88×10^{-4}*(24.06 %)*

Maximum Rotational Displacement (rad)				
Damper	**Resonance Case**		**Non-Resonance Case**	
	Uncontrolled	Controlled	Uncontrolled	Controlled
NLVD	4.20×10^{-4}	1.47×10^{-5} *(96.5%)*	2.45×10^{-4}	9.26×10^{-6} *(96.22 %)*
SAVD		1.94×10^{-4} *(53.8%)*		1.09×10^{-4} *(55.51 %)*
SASD		2.48×10^{-4} *(40.95%)*		1.51×10^{-4} *(38.36 %)*

Maximum Trans. Acceleration (m/s^2)				
Damper	**Resonance Case**		**Non-Resonance Case**	
	Uncontrolled	Controlled	Uncontrolled	Controlled
NLVD	0.3189	0.1184*(62.87 %)*	0.2954	0.1452*(50.85 %)*
SAVD		0.2857*(10.41 %)*		0.2845*(3.69 %)*
SASD		0.3591*(-12.60 %)*		0.3346*(-13.27 %)*

Maximum Rot. Acceleration (rad/s^2)				
Damper	**Resonance Case**		**Non-Resonance Case**	
	Uncontrolled	Controlled	Uncontrolled	Controlled
NLVD	0.0673	0.0191*(71.62 %)*	0.0252	0.0188*(25.40 %)*
SAVD		0.0412*(38.78 %)*		0.0199*(21.03 %)*
SASD		0.0681*(-45.76 %)*		0.0392*(-55.56 %)*

(NOTE: values written in bracket indicates the percentage reduction)

Table shows the maximum value of translational displacement, rotational displacement, translational acceleration and rotational acceleration response of building under Resonance and Non-Resonance cases. It is observed from the table that the controlled and uncontrolled displacement in resonance case is much higher than non-resonance cases. It is further observed that the displacement and acceleration in resonance case can be significantly reduced by dampers as compared to non-resonance case. Hence, the dampers are quite effective in reducing the response under resonance case.

IV. CONCLUSION

The single storey asymmetric building installed with damper (NLVD, SAVD & SASD) under the harmonic excitation is investigated. The harmonic response is evaluated to study the comparative performance of NLVD, SAVD and SASD for asymmetric system. From the numerical study the following conclusion can be drawn:

- The NLVD, SASD & SASD are quite effective in reducing various responses for resonance as well as non – resonance case.
- Building installed with the NLVD significantly reduces lateral-torsional displacement and acceleration in both resonance and non-resonance condition as compared to SAVD and SASD.
- The building installed with the SASD, response of building like lateral-torsional acceleration may increase as compared to uncontrolled building in both conditions.

REFERENCES

[1] W H Liao and C Y Lai, “Harmonic analysis of a magnetorheological damper for vibration control” Smart Mater. Struct. 11- 288–296 (2002)

[2] Ricciardelli, F., Pizzimenti, A.D., Mattei, M., “Passive and active mass damper control of the response of tall buildings to wind gustiness.” Eng. Struct. 25, 1199–1209 (2003)

[3] M. Eissa, H. S. Bauomy, Y. A. Amer, “Active control of an aircraft tail subject to harmonic excitation” Acta Mech Sin (2007) 23:451–462 (2007)

[4] Elizabeth K. Ervin, J.A. Wickert, “Repetitive impact response of a beam structure subjected to harmonic base excitation” E.K. Ervin, J.A. Wickert / Journal of Sound and Vibration 307 - 2–19 (2007)

[5] J¨orn Scheller, Uwe Starossek, “A versatile active mass damper for structural vibration control” Proceedings of the 8th International Conference on Structural Dynamics, EURODYN 2011, ISBN 978-90-760-1931-4 (2011)

[6] Gary C. Hart & Kevin Wong, Structural Dynamics for Structural Engineers, John Wiley & Sons, Inc.