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SEISMIC RESPONSE OF TWO WAY ASYMMETRIC MULTI-STORIED BUILDING INSTALLED WITH NON-LINEAR VISCOUS AND SEMI-ACTIVE STIFFNESS DAMPERS SUBJECTED TO BI-DIRECTIONAL EARTHQUAKES

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ABSTRACT

The seismic response of 10 storied, two way asymmetric building with Non-linear fluid viscous dampers (NLVDs) and semi active stiffness dampers (SASDs) is investigated considering bi-directional seismic ground motion. The control law of switching parameter is considered for semi-active stiffness dampers. The governing equation of motion is derived based on the mathematical model of 10 storied, two way asymmetric building. The response of building is obtained by using state space method for solution of governing equation of motion under different system parameters. The important system parameters are eccentricity of superstructure. To study the effectiveness of those parameters in building are evaluated on peak controlled and uncontrolled response of lateral and torsional displacements, their acceleration and also evaluated control forces in building system for both direction. The comparative study is evaluated for two way asymmetric building installed with Non-linear fluid viscous dampers (NLVDs) and Semi-active stiffness dampers (SASDs). It is shown that the semi active stiffness dampers are quite effective in reducing the responses. Effectiveness of dampers depends on structural system.

***Keywords**: Bi-directional seismic excitation, Non–linear Fluid viscous dampers (NLVDs), Seismic response, Semi-active stiffness dampers (SASDs),Two-way asymmetry.*

I. INTRODUCTION

The safety of the multi-storied structures against natural hazards, such as earthquake forces and wind is a challenges among the researchers and structural designers. The significant concern in the design and analysis of the structures is to have enough stability against wind and seismic forces. Basically there are two types of structures as per geometry, (i) Symmetric structures (ii) Asymmetric structures. Asymmetric structures are also further divided in one way asymmetric and two way asymmetric. Two way asymmetric structures are increasingly vulnerable to serious damage during seismic excitation. The uneven distribution of mass as well as stiffness of the structural elements cause the asymmetry in structure. The prime focus of the structural design engineer is to decrease the torsional response mainly by reduce the eccentricity which is generated due to uneven distribution of mass as well as stiffness. But in many cases if is not possible to avoid that eccentricity in super structure due to the stringent architectural and functional demand. Hence that cases, utilization of control devices is the possible solution for reduce the lateral torsional response of structures.

II. LITERATURE REVIEW

In past numerous researchers have been identified the effectiveness of base isolation, passive control and active control devices are used for structures.(Jangid and Datta, 1994; Goel, 1998), Effectiveness of passive damper(viscous damper) in super high rise buildings (Jiemin et al,2018; Priestley and Grant,2005), Performance of Non-liner fluid viscous dampers in steel structure (Abdelouahab and Nadir,2014; Walsh et al,2013), Seismic response of asymmetric building with semi active stiffness dampers (Mevada and Jangid,2012), Semi active stiffness damper in high rise building (Samali et al,2002). Although, above numerical studys show that effectiveness of passive damper (NLVDs) and semi-active stiffness damper (SASDs) systems installed in building for controlling the torsional responses. However, no work has been reported to the study the comparative parameters of

NLVDs and SASDs for multi-storied two way asymmetric buildings. Further, the effects of the Bi-directional earthquakes on torsional coupled two way asymmetric multi-storied buildings having semi-active stiffness dampers (SASDs) system are also not studied. Based on above literature review, further investigation has been carried out for the seismic response of 10 storied two way asymmetric building is examined under different bi-directional earthquake ground excitation. The objective of study is outlined as to investigate the comparative seismic response of 10 storiedtwo way asymmetric building installed with passive Non-linear fluid viscous damper (NLVDs) and semi active stiffness dampers(SASDs) in controlling lateral, torsional and edge displacements and accelerations.

III. STRUCTURAL MODEL

The framework considered is a linearly elastic 10 storied two way asymmetric building comprises of rigid deck slab supported on columns plan and elevation of building as shown in Figure 1. The mass of slab is assumed to be consistently distributed and thus the centre of mass (CM) is coincides with the geometrical centre of the rigid floor slab. Location and size of columns are taken in such way that it produces the stiffness asymmetry with respect to CM in x-direction as well as in y-direction and thus, the centre of stiffness (centre of rigidity)(CR) is located at an eccentric distance e_x from the CM in x-direction and an eccentric distance e_y from CM in y-direction. The system considered in this paper is two way asymmetric hence, three degree of freedom considered for each rigid supported slab system. System is excited by bi-directional horizontal components of seismic ground motion. Thus, that three degree of freedom in structural model namely are the lateral displacement in x-direction, u_x the lateral displacement in y-direction, u_y and torsional displacement, u_θ. Edge nearer to CR is denoted as stiff edge and Edge of building far from the CR is denoted as flexible edge. The governing equation of motion of the system are considered in matrix form as

$$[M]\{\ddot{u}\}+[C]\{\dot{u}\}+[K]\{u\}+[\Lambda]\{F_d\} = -[M][\Gamma]\{\ddot{u}_g\} \quad (1)$$

Where, $[M]$ is Mass matrix of system, $[C]$ is Damping matrix of the system, $[K]$ is Stiffness matrix of system, u=$\{u_x \quad u_y \quad u_\theta\}^T$ is displacement vector, $[\Lambda]$ is Location matrix for control force, $[\Gamma]$ is the Location matrix for applied force, $\ddot{u}_g=\{\ddot{u}_{xg} \quad \ddot{u}_{yg} \quad 0\}^T$ is ground acceleration vector. Where $\ddot{u}_{xg}$ is ground acceleration in x-direction, $\ddot{u}_{yg}$ is ground acceleration in y-direction. $\{F_d\}$ is the Damper control force vector, $\{F_d\} = \{F_{dx} \quad F_{dy} \quad F_{d\theta}\}^T$, where F_{dx}, F_{dy} and $F_{d\theta}$ are resultant control force of dampers along x-direction, y-direction and θ-direction, respectively.

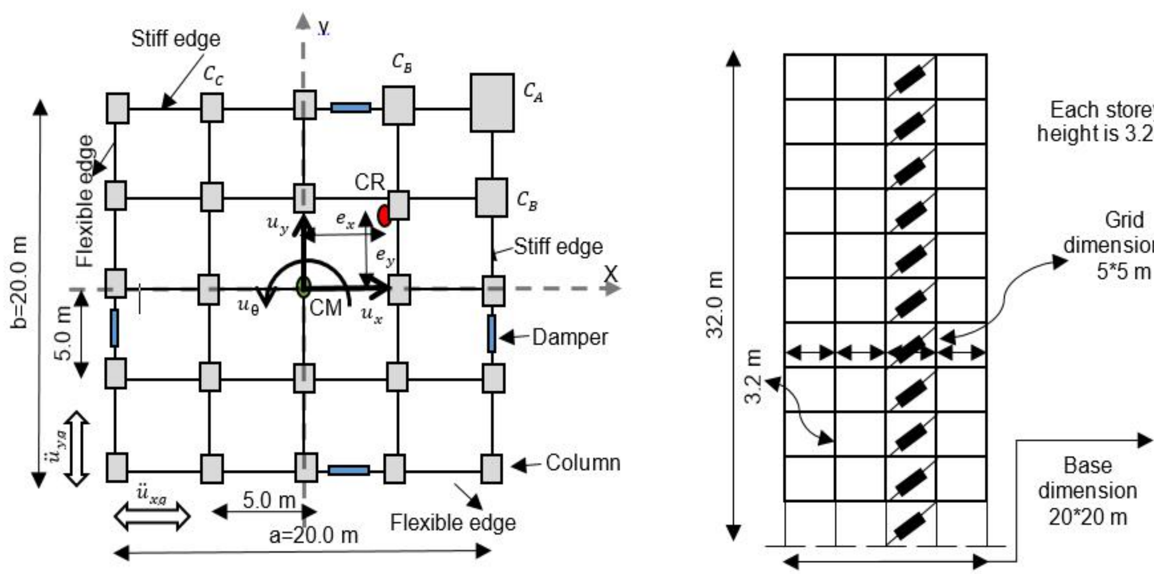

Figure 1Typical floor plan and elevation of asymmetric building showing arrangements of dampers

The mass matrix of system can be expressed as,

$$[M] = \begin{bmatrix} M_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & M_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & M_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & M_4 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & M_5 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & M_6 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & M_7 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & M_8 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & M_9 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & M_{10} \end{bmatrix}$$

(2)

$[M]$=size of mass matrix is $[30 * 30]$

Where, $M_1, M_2, ..., M_{10} = \begin{bmatrix} m & 0 & 0 \\ 0 & m & 0 \\ 0 & 0 & mr^2 \end{bmatrix}$

Where $M_1, M_2, ..., M_{10}$ represents the mass matrix of typical floor, m represents the lumped mass of the typical floor slab; r is mass radius of gyration about a vertical axis through CM which is given by, $r = \sqrt{(a^2 + b^2)/12}$, where a and b are defined as plan dimension of building.The stiffness matrix of the system is defined as follows,

$$[K] = \begin{bmatrix} K_1+K_2 & -K_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -K_2 & K_2+K_3 & -K_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -K_3 & K_3+K_4 & -K_4 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -K_4 & K_4+K_5 & -K_5 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -K_5 & K_5+K_6 & -K_6 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -K_6 & K_6+K_7 & -K_7 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -K_7 & K_7+K_8 & -K_8 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -K_8 & K_8+K_9 & -K_9 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -K_9 & K_9+K_{10} & -K_{10} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -K_{10} & K_{10} \end{bmatrix}$$

(3)

Where, $K_1, K_2, ..., K_{10} = \begin{bmatrix} K_{xx} & K_{xy} & K_{x\theta} \\ K_{yx} & K_{yy} & K_{y\theta} \\ K_{\theta x} & K_{\theta y} & K_{\theta\theta} \end{bmatrix} = \begin{bmatrix} \sum K_{Xi} & 0 & \sum K_{Xi} Y_i \\ 0 & \sum K_{Yi} & \sum K_{Yi} X_i \\ \sum K_{Xi} Y_i & \sum K_{Yi} X_i & \sum K_{Xi} Y_i^2 + \sum K_{Yi} X_i^2 \end{bmatrix}$

Where K represents the total lateral stiffness of system in x and y direction, $K_1, K_2, ..., K_{10}$ is the lateral stiffness of the typical floor, $\sum K_{Xi}$ denotes sum of lateral stiffness in x-direction, $\sum K_{Yi}$ denotes sum of lateral stiffness in y-direction, X_i denotes eccentricity between CM and CR in x-direction, Y_i denotes eccentricity between CM and CR in y-direction.The damping of the system is not known explicitly and it is obtained from the Rayleigh's damping considering mass and stiffness as,

$$[C] = a_0 [M] + a_1 [K] \quad (4)$$

$$a_0 = \frac{2\xi\omega_i\omega_j}{\omega_i + \omega_j} \quad a_1 = \frac{2\xi}{\omega_i + \omega_j} \quad (5)$$

In which a_0 and a_1 are the coefficients relies upon damping ratio of two vibration modes and ξ. ω_i And ω_j represents the natural frequency of the i and j modes of vibration. For the present investigation 5 % damping is considered for all modes of vibration of system. The governing equations of motion is solved using state space method (Hart and Wong, 2000; Lu, 2004) as follows,

$$\dot{z}(t) = A\{z(t)\} - B\{F(t)\} - E\{\ddot{x}_g\} \quad (6)$$

Where, $z = \{u \quad \dot{u}\}^T$ is a state vector, A is the system matrix; B is the distribution matrix of control forces; and E is distribution matrix of excitations. These matrices are expressed as,

$$A = \begin{bmatrix} 0 & I \\ -M^{-1}K & -M^{-1}C \end{bmatrix} B = \begin{bmatrix} 0 \\ M^{-1}\Lambda \end{bmatrix} \text{ and } E = \begin{bmatrix} 0 \\ \Gamma \end{bmatrix} \quad (7)$$

The equation is discretized in time and the excitation and control forces are thought to be steady within any time interval, the solution might be written in an incremental form (Hart and Wong, 2000; Lu, 2004),

$$z_{(k+1)} = A_d z_k + E_d \ddot{u}_g + B_d F_d \quad (8)$$

Where k is the time step; and $A_d = e^{A\Delta t}$ is the discrete time system matrix with Δt as interval of time. The constant matrices B_d and E_d are discrete time matrices B and E and can be written as

$$B_d = A^{-1}(A_d - I)\,B \text{ and } E_d = A^{-1}(A_d - I)\,E \quad (9)$$

IV. MODELING OF DAMPER

A. Fluid viscous damper

Fluid viscous damper work on the principal of liquid pass through orifices and give force that dependably oppose structure movement during a seismic action. Figure 2 demonstrates a mathematical model of typical fluid viscous damper. A typical viscous damper comprises of a round and hollow body and piston of cylinder which strokes through a liquid filled chamber. The normally utilized liquid is silicone based liquid which guarantees proper performance and stability. The differential pressure produced over the cylinder head results in the damper force (Symans and Constantinou, 1998; Lee and Taylor, 2001). The force produced in a fluid viscous damper, ($F_{ds} and\ F_{df}$) depends on the relative velocity between the extreme end of a damper and given by

$$F_{di} = C_{di}(\dot{u}_{di})^{\alpha} \quad (10)$$

Where, $C_{di} = 2m\omega_n\xi$ is damper coefficient of the i^{th} damper which is located at particular floor having eccentricity between CM and i^{th}damper.$\dot{u}_{di}$ Is relative velocity between the ends of the damper which is to be considered for a particular damper position, a is the exponent of damper ranging from 0.1 to 1.0 for different seismic application. The exponent value of a is essentially constrained by the design of cylinder head openings. At the point when a=1.0, a damper is called as linear fluid viscous damper (LVD) and with the estimation of a lesser than unity, a damper will act as nonlinear viscous damper (NLVD). Dampers with a bigger than unity have not been seen regularly in seismic reasonable application.

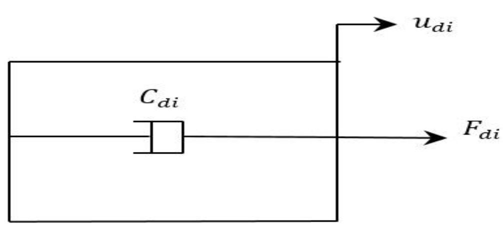

Figure 2 Mathematical model fluid viscous damper

B. Semi-active stiffness damper

Semi-active stiffness damper are used to change the stiffness and in this way natural vibration attributes of the structure. These devices are locked in or released in order to consider or not consider the stiffness of the bracing elements of the structure. The damper comprises of a cylinder and piston system with a valve diversion pipe associating opposite sides of the cylinder. Figure 3 demonstrates the schematic and numerical model of stiffness damper. At the point when the valve is shut, the damper works as a stiffness component in which the stiffness (k_f) is given by the bulk modulus of the liquid in the cylinder. At the point when the valve is open, the cylinder is allowed to move and the damper gives just a little damping without stiffness. The effective stiffness of the gadget comprises of damper stiffness (k_f) and bracing stiffness (k_b) and total stiffness of system is given by following equation

$$k_{hi} = \frac{k_{fi}k_{bi}}{(k_{fi}+k_{bi})} \quad (11)$$

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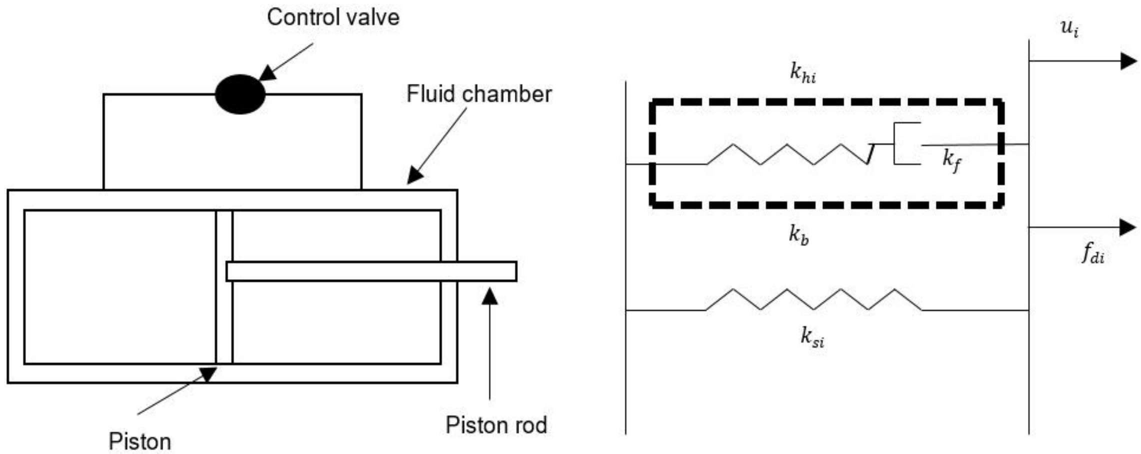

Figure 3 Schematic and mathematical model of semi-active stiffness dampr (Kori and Jangid, 2007)

C. Switching control law for semi-active stiffness damper

In this control, the valve of pressure driven damper is pulsed to open during a specific time step and close during some other time step, which can be considered as switching semi-active stiffness damper (SASD) At the point when a valve of the i^{th} damper is closed, the effective stiffness, k_{hi} is added to the story unit and when a valve is open, the net stiffness, k_{hi} is zero. At a point when the valve is changed off from on, a specific amount of energy is removed from the auxiliary structural system and when it is on, energy is added to the structural system. The control force of i^{th} SASD can be defined as,

$$F_{di} = k_{hi} v_i u_i \tag{12}$$

Where k_{hi} is effective stiffness of i^{th} damper; u_i is the relative displacement at the location of i^{th} damper and $v_i$is the switching parameter of i^{th} damper which is based on the switching control law that can be defined as (Yang et al. 2000)

$$v_{i(t)} = \begin{cases} 1 & if\ u_i \dot{u}_i \geq 0 \\ 0 & other\ wise \end{cases} \tag{13}$$

When $v_{i(t)}$=1, that represents the i^{th} SASD is locked (i.e. valve is closed) and $v_{i(t)}$=0, that represents the i^{th} SASD is unlocked (i.e. valve is open).

V. NUMERICAL STUDY

The seismic response of linearly elastic, idealized10 storied, two-way asymmetric building installed with NLVD and SASD is investigated by numerical simulation study under bi-directional excitation. Here dampers are installed at peripheral to all floor of structural system. The response quantities of interest are lateral and torsional displacements of all floor mass obtained at the CM $\{u_{xi} \quad u_{yi} \quad u_{\theta i}\}$, displacements at stiff and flexible edges of structural system in both direction (u_{xsi}, u_{xfi},u_{ysi} and u_{yfi}), lateral and torsional accelerations of floor mass obtained at the CM ($\ddot{u}_{xi}$, $\ddot{u}_{yi}$ *and* $\ddot{u}_{\theta i}$), control forces of the dampers installed at stiff edge (F_{dsxi} and F_{dsyi}) and at flexible edge (F_{dfxi} and F_{dfyi}) of building.

For x-direction damper

$$\dot{u}_s = \dot{u} - \left(\frac{b}{2}\right) * \dot{\theta} \quad \text{(Velocity in stiff side)} \tag{14}$$

$$\dot{u}_f = \dot{u} + \left(\frac{b}{2}\right) * \dot{\theta} \quad \text{(Velocity in flexible side)} \tag{15}$$

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For y-direction damper

$$\dot{u}_s = \dot{u} + \left(\frac{b}{2}\right) * \dot{\theta} \quad \text{(Velocity in stiff side)} \tag{16}$$

$$\dot{u}_f = \dot{u} - \left(\frac{b}{2}\right) * \dot{\theta} \quad \text{(Velocity in flexible side)} \tag{17}$$

Using above eq. 14 to 17 are useful for calculating lateral velocity in x and y direction of i floor for stiff and flexible side of rigid slab floor system. Here i represents the floor number at which dampers are provided. The response of the system is examined under following parametric variation: damping co-efficient (C_d), exponent co-efficient of viscous damper (α) and stiffness ratio (k_r). The peak responses are obtained corresponding to the important parameters which are listed above for Imperial Valley (1940), Kobe (1995), Loma Prieta (1989) and Northridge (1994) with corresponding ground acceleration values of earthquake ground motions EQ_x in x-direction as well as EQ_yin y-direction. PGA values of each earthquakes are listed in Table 1.

Table 1 Details of earthquake motions considered for the numerical study

Name of Earthquake	Duration in seconds	For x-direction		For y-direction	
		Component	PGA(g)	Component	PGA(g)
Imperial valley ,19 May 1940	40	ELC 180	0.31	ELC 270	0.21
Kobe, 16 January 1995	48	KJM 000	0.82	KJM 90	0.60
Loma prieta, 18 October 1989	25	LGP 000	0.97	LGP 90	0.59
Northridge, 17 January 1994	40	SCS 52	0.61	SCS 142	0.89

For the study here in the aspect ratio of plan dimension is kept as unity and the mass and stiffness of system are considered such as to have required lateral time period. Further, 04 dampers at each storey are installed in the building as shown in Figure 1. Physical quantities of system for analysis are taken as follows, plan dimension of 20m x 20m, height of typical storey considered as 3.2m. Here columns are placed at all four corner of grid size of 5.0m x 5.0m as shown in Figure 1. Size of column is taken as follow, C_A is 0.8m x 0.8m, $C_B$is 0.5m x 0.5m and C_c is 0.4m x 0.4m, to obtain two way asymmetry in structural system.

In order to study optimum value for C_d for NLVDs a parametric study is carried out for two way asymmetric system with lateral time period 1.33 sec. Here lateral time period of structural system is investigate by Eigen extraction method. The responses are obtained for system under four considered earthquake and that variations are shown in figure 4. The responses obtained for controlled displacement (u_x u_y u_θ), acceleration ($\ddot{u}_x$ $\ddot{u}_y$ $\ddot{u}_\theta$) due to bi-directional excitation and its variation against C_d is plotted as shown in Figure 5. Here all responses are obtained for a is taken as 0.5. It can be observed from the Figure 5 that with increase in value ofC_d, that reduction in controlled displacement as well as in acceleration. At particular value of C_d further responses are constant. Hence, from the investigation optimum value C_d taken as 800 kN s/m.

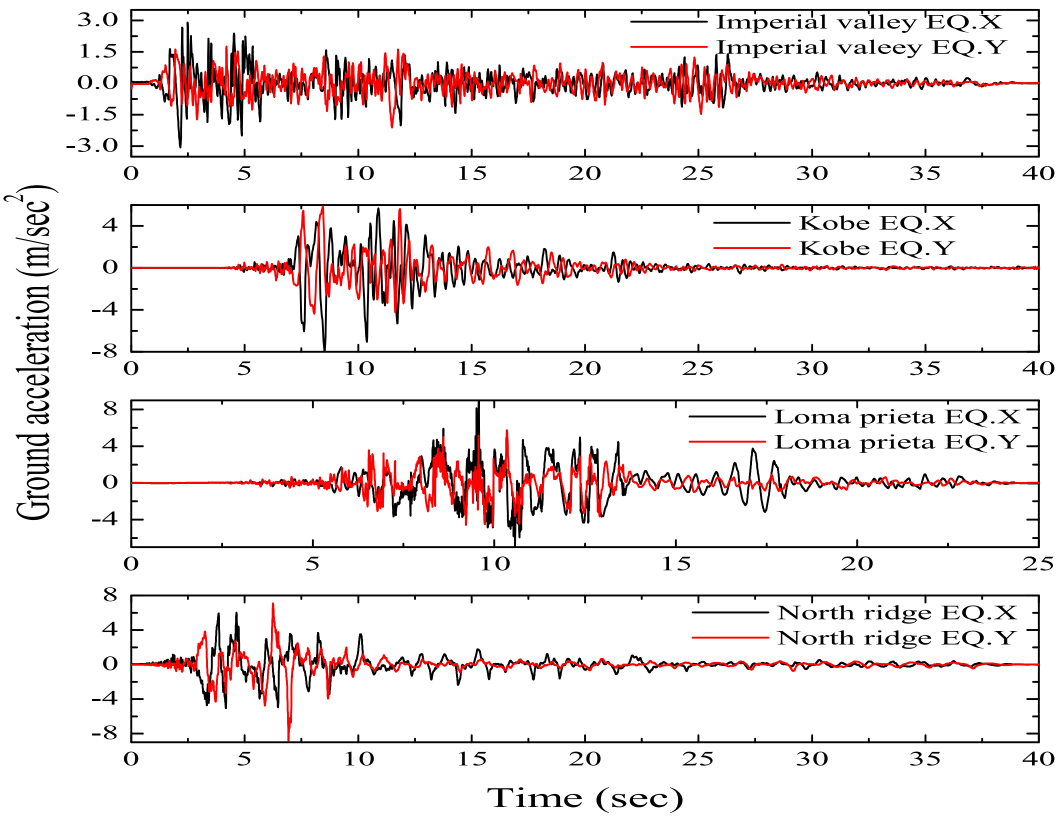

Figure 4 Time history of different earthquakes

In order to examine the effectiveness of NLVDs value of α in present study is taken as 0.5. For semi-active stiffness damper (SASD) effective damper stiffness (k_{hi})plays a vital job while planning the control system. For the present investigation, the stiffness ratio (k_r) is considered as follows,

$$k_r = \frac{k_{hi}}{k_{si}} \tag{18}$$

Where k_{si} is defined as storey stiffness. In order to study the effects of stiffness ratio k_r for SASDs a parametric study is carried out for the two way asymmetry system. The responses are obtained for system under four considered earthquake and there variations are shown in Figure 6. The responses obtained for controlled displacement $(u_x \quad u_y \quad u_\theta)$, acceleration$(\ddot{u}_x \quad \ddot{u}_y \quad \ddot{u}_\theta)$ due to bi-directional excitation and its variation against k_r is plotted as shown in Figure 6. It can be observed from the Figure 6, with increase in ratio of stiffness (k_r) reduction in controlled displacements but in controlled acceleration responses are not reduce if increase in stiffness ratio k_r for two way asymmetric system under four different earthquakes. Hence from the investigation value k_r taken as 0.4.

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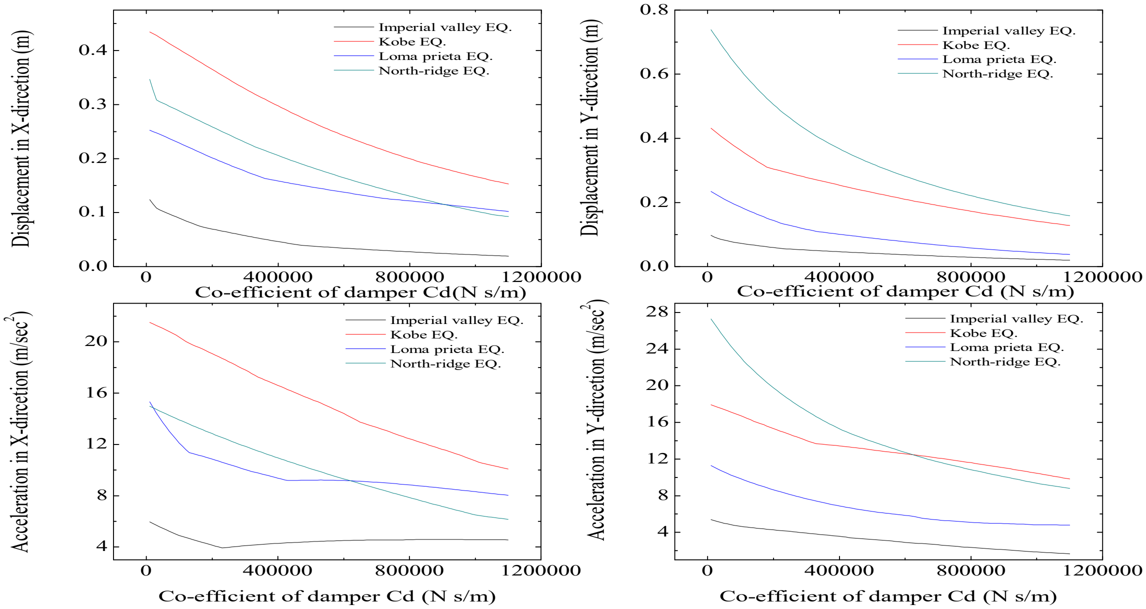

Figure 5 Effect of cd for various displacement and acceleration responses for NLVDs

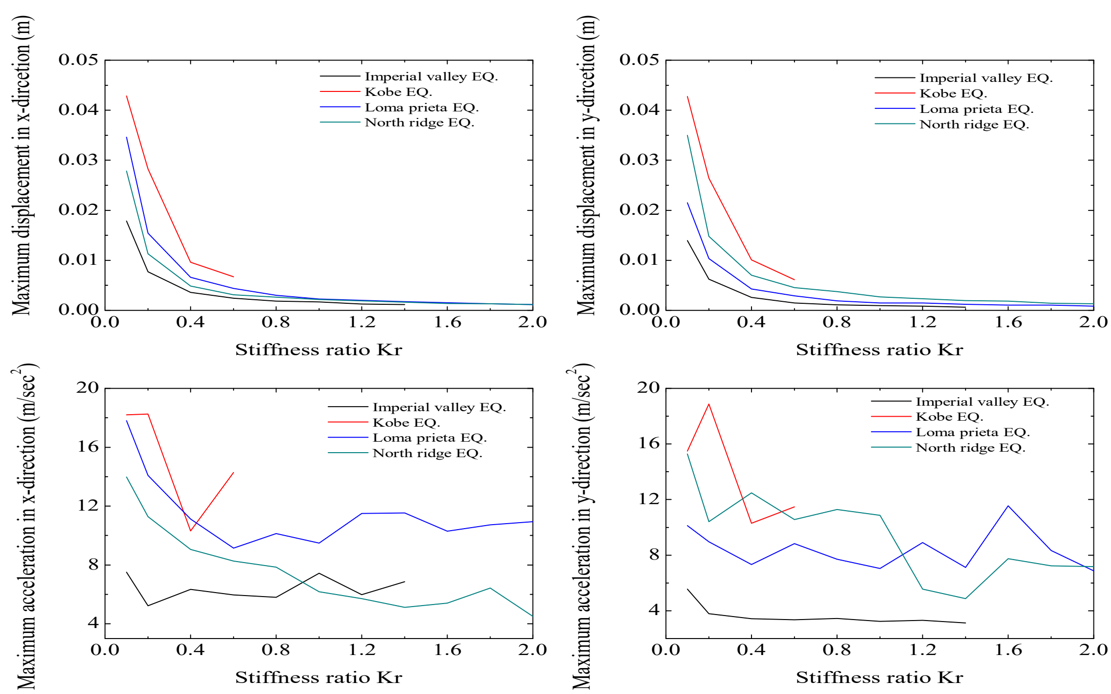

Figure 6 Effect of k_r for various displacement and acceleration responses for SASDs

Figure 7 represents time history for various controlled and uncontrolled displacement and acceleration responses for 10th floor under Imperial Valley, 1940 Earthquake. As shown in figure 7, concluded that installation of NLVD and SASD damper lateral and torsional displacements and lateral acceleration are reduced in controlled structural system. But rotational acceleration response is increase in comparison to uncontrolled system because structural system became stiff in rotational direction in controlled system.

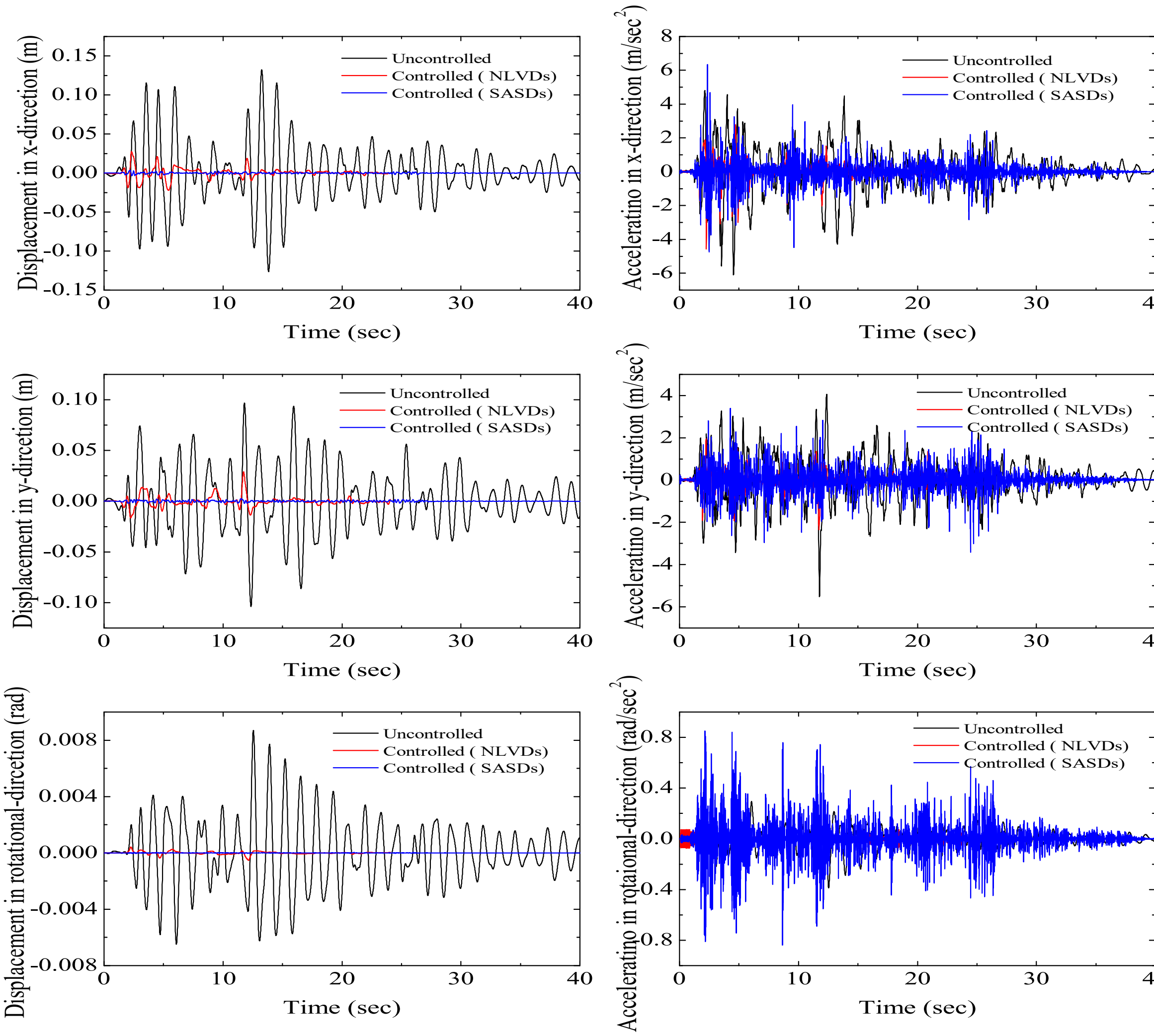

Figure 7 Time history for various controlled and uncontrolled displacement and acceleration for 10th floor under Imperial Valley, 1940 Earthquake

Figure 8 represents the typical hysteresis loops for the normalized 10th floor NLVDs damper force with displacement and velocity for C_d is taken as 800 kN s/m and velocity exponent a taken as 0.5 for different earthquakes. Present investigation dampers are located at outer peripheral all side of floor as well as in all storey. Figure 9 represents the typical hysteresis loops for the normalized 10th floor SASDs damper force with displacement for different earthquakes. In that investigation stiffness ratio of structural system is taken as 0.4.
Table 2 represent the 10th floor lateral displacement response for different control devices. It also represents the % reduction in lateral displacement in x and y direction in controlled system. Table 3 represent the 10th floor lateral acceleration response for different control devices. It also represents the % reduction in lateral acceleration in x and y direction in controlled system. From Table 3 also show that installation of SASD is very sensitive in acceleration response.

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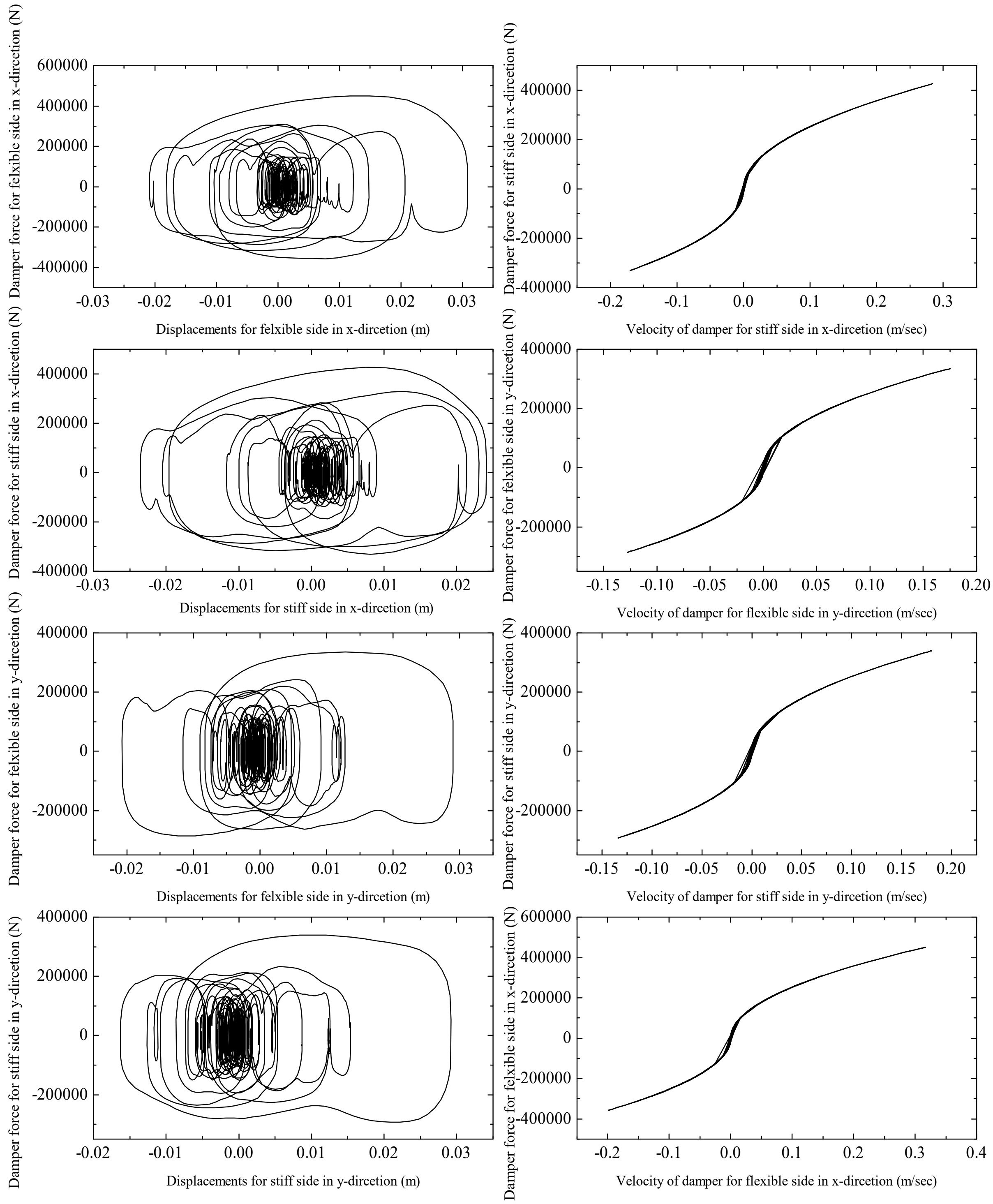

Figure 8 Damper force-displacement and velocity hysteresis loops for NLVDs located at floor 10th on flexible edge and stiff edge on both direction under Imperial Valley, 1940 Earthquake

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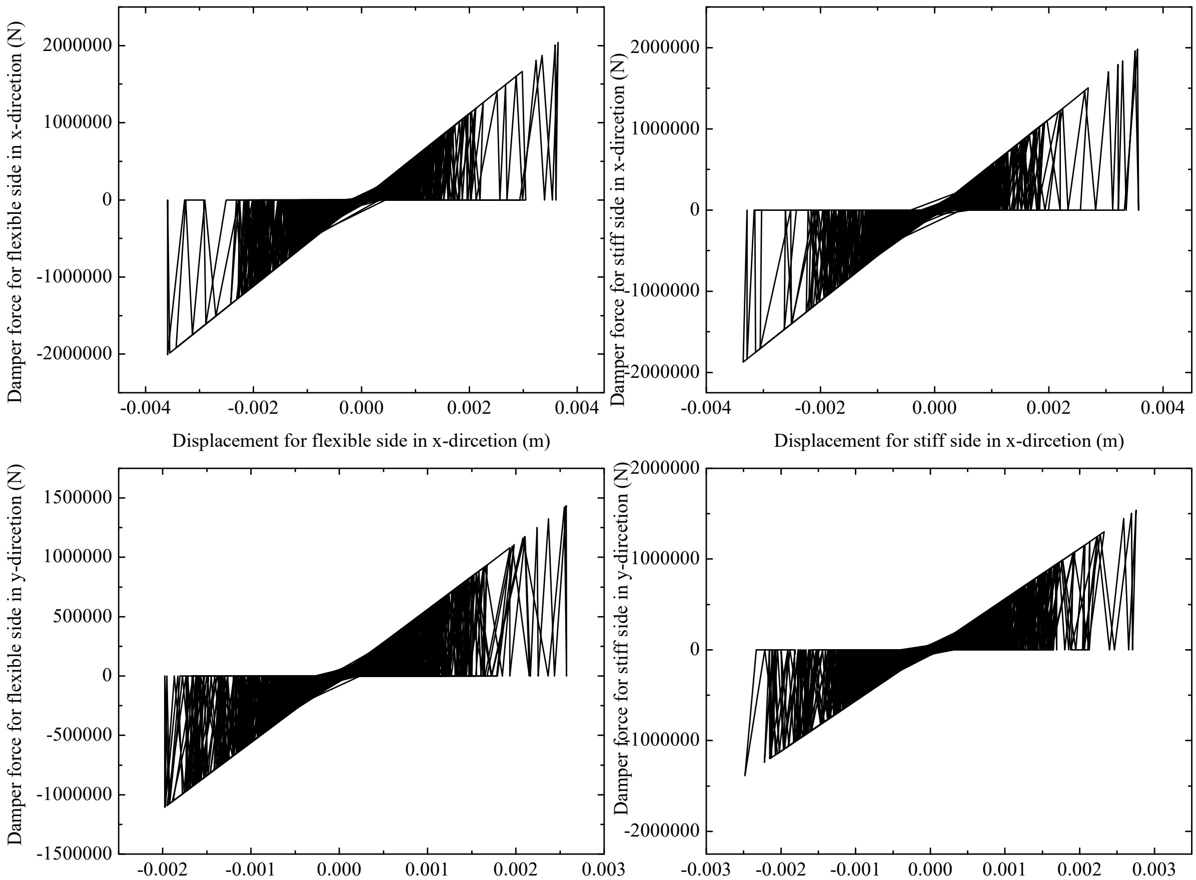

Figure 9 Damper force-displacement hysteresis loops for SASDs located at floor 10th on flexible edge and stiff edge on both direction under Imperial Valley, 1940 Earthquake

Table 2 10th floor peak displacement response for different control devices

		X Direction displacement (m)			Y Direction displacement (m)		
		Uncontrolled	NLVD	SASD	Uncontrolled	NLVD	SASD
Imperial valley earthquake		0.132	0.027	0.0036	0.1038	0.029	0.0026
	% reduction	-	79.24	97.27	-	72.06	97.50
	avg.% reduction	88.26			84.78		
Kobe earthquake		0.437	0.1997	0.00962	0.4398	0.1728	0.01009
	% reduction	-	54.30	97.80	-	60.71	97.71
	avg.% reduction	76.05			79.21		
Loma-prieta earthquake		0.2547	0.1217	0.0066	0.2419	0.0583	0.00427
	% reduction	-	52.22	97.41	-	75.90	98.23
	avg.% reduction	74.81			87.07		
Northridge earthquake		0.3682	0.1305	0.0048	0.7547	0.2211	0.00704
	% reduction	-	64.56	98.68	-	70.70	99.07
	avg.% reduction	81.62			84.89		

Table 3 10th floor peak acceleration response for different control devices

		X Direction acceleration(m/sec2)			Y Direction acceleration(m/sec2)		
		Uncontrolled	NLVD	SASD	Uncontrolled	NLVD	SASD
Imperial valley earthquake		6.0954	4.5731	6.3485	5.5143	2.346	3.4236
	% reduction	-	24.97	-4.15	-	57.45607	37.91415
	avg.% reduction	10.41			47.69		
Kobe earthquake		21.6143	12.4355	10.3184	18.0515	11.6016	10.2909
	% reduction	-	42.47	52.26	-	35.73	42.99
	avg.% reduction	47.36			39.36		
Loma-prieta earthquake		11.8487	8.8396	11.123	11.4784	5.0919	7.3371
	% reduction	-	25.40	6.12	-	55.64	36.08
	avg.% reduction	15.76			45.86		
Northridge earthquake		15.0997	7.855	9.0592	27.8377	10.842	12.4789
	% reduction	-	47.98	40.00	-	61.05	55.17
	avg.% reduction	43.99			58.11		

VI. CONCLUSIONS

The seismic response of linearly elastic, 10 storied, two-way asymmetric structure with non-linear viscous dampers and semi-active stiffness damper under bi-directional earthquake excitations are investigated. The responses are assessed with parametric variations to study the effectiveness of NLVDs and SASDs for two way asymmetric system. There are two parameters considered for NLVDs in numerical study are coefficient of damper (C_d) and exponent of velocity (α) and another parameter considered for SASDs in numerical study is stiffness ratio (k_r). From the present numerical study, the following conclusion can be made for two way asymmetric system,

1. Semi-active stiffness damper is more effective than Non-linear viscous damper to reducing the edge displacement and torsional displacement in both x and y direction.
2. Non-linear viscous damper is more effective than semi-active stiffness damper for reducing the edge acceleration in both x and y direction.
3. There exist optimum value for exponent coefficient (α) and damping coefficient (C_d) for Non-linear viscous damper as well as for stiffness ratio (k_r) for semi-active stiffness damper.

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