Seismic Response Control of the Building using Passive Devices

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Abstract-- **Earthquakes are one of the major natural hazards and responsible for the lives of thousands of people and damage to the structures. Buildings being one of the prime structures for mankind, it is necessary that they are designed to resist earthquake forces. Building subjected to earthquake excitation show excessive structural response (vibrations); though inherent damping of the building helps to reduce to some extent vibrations caused. However, building subjected to strong motions, the inherent damping of the building is insufficient to control the structural response and hence, additional stiffness and/or damping are demanded. Three basic technologies are used to impart additional stiffness and/or damping in the building. These are Base Isolation, Passive Energy Dissipation Devices and Active Control Devices. In Passive Energy Dissipation systems the motion of the building is controlled by adding passive device to the building which contributes to additional stiffness and damping. Passive energy dissipation devices operates on principles such as, yielding of metals, frictional sliding and deformation of Viscoelastic (VE) solids or fluids. Nowadays there are numbers of manufactured damper available in the market like Friction, Yielding Metallic, Viscoelastic (VE) and Viscous Dampers.**

The main objective of the paper is to control the seismic response of the building subjected to different types (strong motion and pulse) of earthquake excitations using Passive Energy Dissipation Devices like Viscous and Viscoelastic (VE) Dampers. A three sto.rey shear building is considered and solved using Newmark-Beta numerical method through MATLAB. Response quantities like displacement, velocity, acceleration, interstorey drift and damper force are extracted. Comparison of buildings with Viscous and VE dampers with that of uncontrolled building is carried out for response quantities. It has been found that extra amount of stiffness and damping provided by passive dampers directly influences the seismic response of the building. The response quantities show reduction up to half (~ 50%) as compared to uncontrolled response of the building.

Index Terms—**Earthquake Excitations, Newmark-Beta Method, Passive Energy Dissipation Devices, Shear building**

I. Introduction

Earhtquake is one of the major natural hazards to the life on the earth and has affected countless cities and villages of almost every continent. The damaged caused by earthquakes are mostly to man mad structures. Hundreds of small earthquake occurs around the world every day and every year earthquakes take the lives of thousands of people. Therefore, it is necessary to design structures that are earthquake resistant. Earthquake engineering has gain lots of attention in recent years since it ensures design of safe structures which can safely withstand earthquakes of reasonable magnitude.

Conventional seismic design attempts to make building that do not collapse under strong earthquake shaking, but may sustain damage to non-structural elements and to some structural members in the building. This may cause the building to be non-functional after the earthquake, which may be problematic in some structures, like Hospitals, which need to remain functional after an earthquake. Special techniques are required to design buildings such that they remain practically undamaged even in a severe earthquake. Three basic technologies are used to protect buildings from damaging earthquake effects. These are Base Isolation, Passive Energy Dissipation Devices and Active Control Devices. The concept behind base isolation is to detach (isolate) the building from ground in such a way that earthquake ground motions are not transmitted up through the building or at least greatly reduced. In passive energy dissipation systems the motion of structure is controlled by adding devices to the structure in the form of stiffness and damping. Passive energy dissipation devices can be effective against wind and earthquake induced motion.

In this paper main objective is to study response reduction of the building subjected to various earthquake excitations using passive energy dissipation devices like Viscous and Viscoelastic (VE) dampers. In order to achieve the objective, a three storey shear building subjected to earthquake excitation is considered and solved using Newmark-Beta numerical method through MATLAB. Uncontrolled response and controlled response using passive devices are obtained. Response quantities obtained for each case (uncontrolled, controlled) are compared for performance appraisal of passive devices.

II. Literature review

Design for strength alone does not necessarily ensure that the building will respond dynamically in such a way that the comfort and safety of the occupants is maintained. For example, during the Loma Prieta earthquake (1989), a 47-storey building in San Francisco experienced peak acceleration of about 0.1% g in the basement and 0.45% g on the top floor, which indicates that strong ground motion produce harmful acceleration at the upper stories of the building. Similar comments can be made about buildings responding to earthquakes like Northridge and Kobe. Thus, alternative means of increasing resistance of building to earthquake excitation while maintaining desirable dynamic properties using various active, semi-active, passive and hybrid control schemes offer great promise.

G.W. Housner et. al. [1] presented a concise point of departure for researchers and practitioners alike wishing to assess the current state of the art in the control and monitoring of civil engineering structures. It also points out where future research and application efforts are likely to prove fruitful. The paper deals with sufficient details passive energy dissipation devices and their model, active control, hybrid and semi-active control systems, sensors for structural control, smart material systems, health monitoring, damage detection.

J. Marko et. al. [2] focuses on the comprehensive study on the seismic mitigation of medium rise frame-shear wall structures using embedded dampers. Two building structures with embedded viscoelastic (VE) and friction dampers in different configurations and placed in various locations throughout the structures were subjected to five different earthquake loadings. Another study treated seismic mitigation by using six different damping systems, namely, friction and VE diagonal dampers, friction and VE chevron brace dampers, hybrid friction –VE dampers and lower toggle VE dampers. These damping systems were embedded into six different placements (one at a time) within cut outs of shear walls to mitigate the seismic response of medium rise building. A VE damper was modeled as linear spring and dash – pot in parallel (i.e., Kevin Model). Damper properties such as stiffness, damping co-efficient, location, configuration and size were varied and results for displacement and accelerations at top storey were obtained. A direct integration dynamic analysis was selected to obtain the response of the structure under seismic loading.

B. Samali and K. C. S. Kwok [3] discussed about the use of VE dampers in reducing wind and earthquake induced motion of the building. The methodology for the design of VE dampers used was as given by Abbas and Kelly, which includes Single Degree of Freedom (SDOF) model with rigid brace and two DOF model with a deformable brace to capture the response of VE damped structures. Extensive parametric analysis shows that the addition of VE dampers consistently reduces the displacement demands. The design process was illustrated with the design of VE dampers and associated braces for a nine-storey moment resisting steel frame. Extensive nonlinear time-history analysis of a viscoelastically damped frame subjected to different earthquake ground motions showed significant reduction in the storey shear force and peak interstorey drift. It has been shown that about 85% of input energy is dissipated through VE devices.

III. PASSIVE CONTROL SYSTEMS

Dynamic load produces vibration in the structure which causes the damage or collapse of the structure. A large amount of energy is imparted into structure during these vibrations. To reduce these vibrations it becomes important for the structures to absorb or dissipate energy. A widely considered strategy consists of incorporating external elements to the structure to control its dynamic response. The function of seismic passive energy dissipation system is to reduce structural response due to earthquake, wind and other dynamic loads. Passive control system develops control forces at the point of attachment of the system. The power needed to generate these forces is provided by the motion of the points of attachment during dynamic excitation. In recent years, serious efforts have been undertaken to develop the concept of energy dissipation or supplemental damping into a workable technology and a number of such devices have been installed in structures throughout the word [4,5].

Passive energy dissipation devices may be simply classified as, (i) Displacement Dependent Devices – includes Friction Damper and Metallic Damper, (ii) Velocity Dependent Devices – includes Viscous Damper and Solid and Fluid VE Damper (iii) Dynamic Vibration Absorber (DVA) – includes Shape Memory Alloys and Tuned Mass or Tune Liquid Oscillator Type Damper. Displacement Dependent devices dissipate energy through the inelastic behavior of the damper elements (like in metallic damper) because their energy dissipation depends primarily on relative displacements within the device and not on their relative velocities. Velocity dependent devices like Viscous and VE elastic dampers dissipate energy through deformation of VE polymers, deformation of viscous fluids, or fluid orificing. Their energy dissipation depends on both relative displacements and relative velocities within the device. DVA consists of an auxiliary mass-spring system which tends to neutralize the vibration of a structure to which it is attached. Table I shows the supplemental energy dissipation devices and its principle operation. Arrangement of VE damping system in building structure is shown in Fig. 1.

Table I Passive Devices and It's Principle of Operation

Type	Device	Principle of operation
Hysteretic	Metallic yielding	Yielding of metals
	Friction	Frictional sliding
VE	VE solids	Deformations of VE polymers
	Viscous and VE fluids	Deformation of viscous fluid

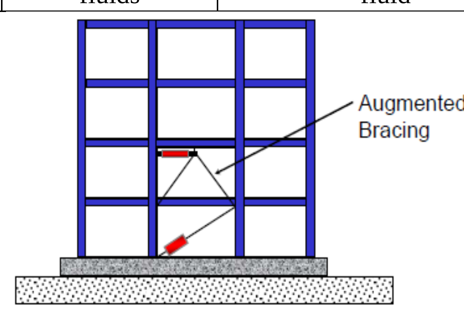

Fig. 1 DAMPER PLACEMENT WITHIN BUILDING

Viscous Fluid Damper – Fluid viscous dampers are fluid-filled cylinders with two chambers that are separated by a moving piston with directional orifices, and an accumulator chamber. As the head moves longitudinally within the shaft, viscous fluid flows from one chamber to the other. The force in the damper is a result of the pressure differential between chambers, which is a function of the orifices in the piston head and the velocity of the piston head [6,7]. The damping force developed by the viscous damper depends on the physical properties of the fluid used in the damper. The most common type of viscous fluid damper and its parts are shown in Fig. 2. It dissipated energy through movement of the piston in the highly viscous fluid. If the fluid is purely viscous (for instance, Newtonian), then the output force of the damper is directly proportional to the velocity of the piston.

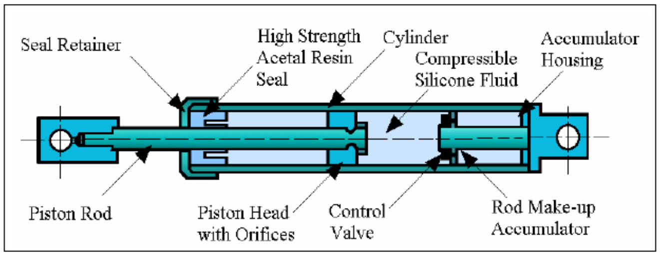

Fig. 2 SCHEMATIC OF VISCOUS FLUID DAMPER [7]

Mathematical Model and Behavior – Different mathematical models have been proposed in literature to predict the behavior of viscous device. Fig. 3 shows classical Maxwell model, in which dashpot and spring elements are joined in series. However, for typical structural applications the viscous damper can be modeled as a simple dashpot element in which the damping force is directly proportional to the velocity of the piston as given in Fig, 3.

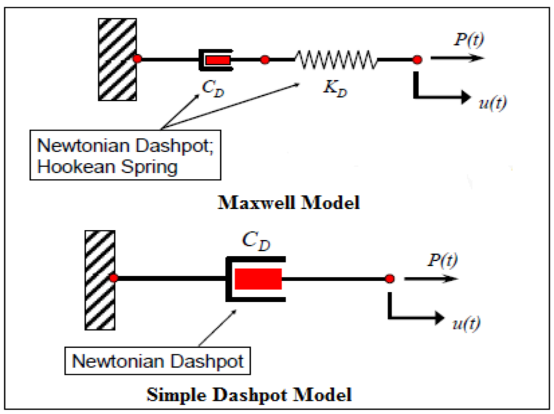

Fig. 3 SIMPLE DASHPOT AND MAXWELL MODEL FOR VISCOUS DAMPER [8]

The force in the fluid viscous damper may be expressed as [8],

$$F(t) = C_d |\dot{u}|^{\alpha} \, sgn(\dot{u}) \tag{1}$$

where, C_d is the damping co-efficient for the damper, α is the velocity exponent for the damping that ranges from 0.1 to 2, $\dot{u}$ is the relative velocity between each end of the device, and sgn is signum function that, defines the sign of the relative velocity tern. A value of α = 1.0 represents the linear viscous damper. The value of resisting force in linear viscous fluid damper varies with respect to the translational velocity of the damper at any point in time is given by,

$$F(t) = C_d \dot{u}(t) \tag{2}$$

where, $F(t)$ is the resistance force for linear viscous damper, C_d and u are the damping co-efficient and displacement of the damper, respectively.

The energy dissipated by the damper can be find out from the following equation,

$$E_D = \int |F(t)| \, du \tag{3}$$

The area contained within the hysteretic loop present in Fig. 4 measures the energy dissipated per cycle in the viscous damper.

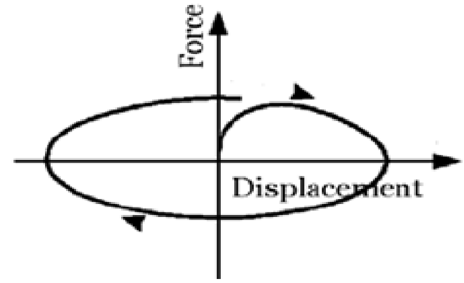

Fig. 4 HYSTERESIS LOOP FOR VISCOUS DAMPER [5]

Viscoelastic Damper – Application of VE damper to civil engineering structures appears to have begun in 1969 when 10,000 VE dampers installed in each of the twin towers of the World Trade Centre in New York to help resist wind loads. For seismic applications, larger damping is required as compared to those required for mitigating wind induced vibrations. VE materials used in damper are typically copolymers or glassy substances which dissipate energy when subjected to shear deformation. A typical VE damper is shown in Fig. 5, which consists of VE layers bonded with steel plates. The structural vibration induces relative motion between the outer steel flanges and the center plate.

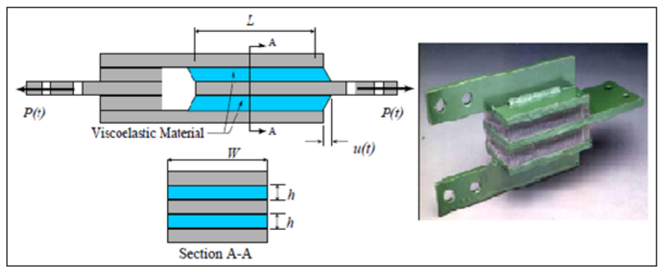

Fig. 5 SCHEMATIC OF VISCOELASTIC DAMPER [8]

Mathematical Model and Behavior – In VE materials energy is dissipated through large shear strains. VE dampers cause a small increase in structural stiffness due to the inherent stiffness of the VE material. As suggested in the FEMA 273 guidelines [8], solid VE devices may be modeled using classical Kelvin model, in which a linear spring is placed in parallel with a viscous dashpot, as shown in Fig. 6.

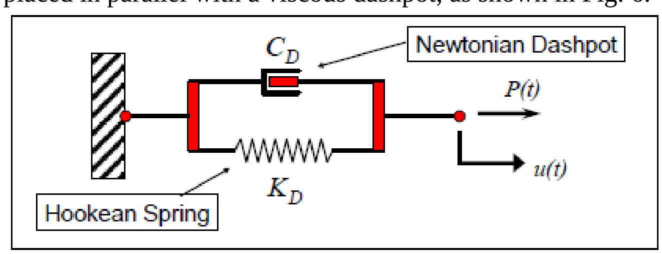

Fig. 6 KELVIN MODEL - VISCOELASTIC DAMPER [8]

Most of the mathematical properties of VE material is complex and may vary with environmental temperature and excitation frequency. Hysteresis loop is obtained when VE damper subjected to periodic displacement. Area of this hysteresis loop represents the actual energy lost which directly depends on VE properties. The main VE properties used in designing the VE damper are storage modulus, G', which provides the elastic shear stiffness of the material, and shear loss modulus, G'', which represents the velocity dependent devices or viscous stiffness of material. The stress strain relation can be expressed as

$$\tau(t) = G' \gamma(t) \pm G'' (\gamma'(t))/f \quad (4)$$

where $\tau(t)$ is the shear stress as a function of time, t ; $\gamma(t)$ is the shear strain as a function of time; and f is the circular frequency in rad/sec. Stress strain relation is an ellipse with a nonzero slop. The slop is associated with G' term, and the area of the ellipse is related to the G'' term. Thus, a simple relationship between the energy dissipated by VE material and viscous dampers can be established.

Abbas et. al. defines the stiffness co-efficient k_d and damping co-efficient C_d for a viscoelastic damper. Force – displacement relationship of VE device may be expressed as,

(5)

In which

$$K_d(f) = \frac{G'A}{t}, \quad C_d(f) = G''A/(f\,t) \quad (6)$$

where, A is the shear area of VE material, t is the thickness of VE material, f is the loading frequency of VE damper, G' is the shear modulus, G'' is the shear loss modulus and x is the relative displacement at end. Loss factor, η , is define as a ration of the shear loss modulus to the shear storage modulus (G''/G') . The following equations can be used to obtain the moduli of the VE material as defined by Abbas et al.

$$G' = 16\, f^{0.51} \gamma^{-0.23} e^{\frac{72.46}{T}} \quad (7)$$

$$G'' = 18.5\, f^{0.51} \gamma^{(-0.20)} e^{(73.89/T)} \quad (8)$$

where, γ is the shear strain, T is temperature. It is evident from Eqs. (7) and (8) that temperature influences the properties of VE material.

IV. PROBLEM STATEMENT

In order to assess the efficacy of passive energy dissipation devices in controlling seismic response of the building, a three storey building with following geometric dimension is considered.

No. of storey = 3,
Storey height = 3 m,
Slab thickness = 120 mm,
Nos. of bays in X- and Y - direction = 3,
Bay width in X- and Y- direction = 4 m,
Column sizes = 0.3 m × 0.3 m,
Beam sizes = 0.23 m × 0.3 m,
Grade of concrete and steel are M20 and Fe415, respectively, Live Load on typical floor = 3 kN/m^2.

The plan and 3D view of the building with above mentioned geometry is shown in Fig. 7 below.

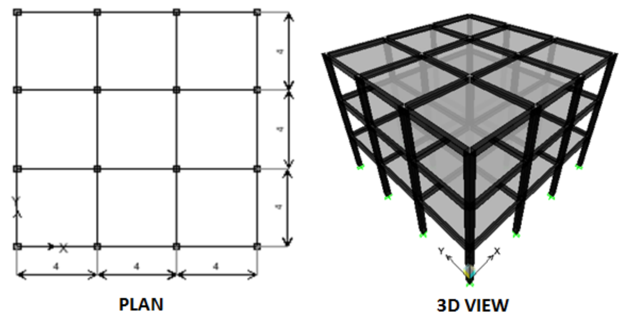

Fig. 7 PLAN AND 3D VIEW OF THE THREE STOREY BUILDING

The building is symmetrical in plan. The dynamic properties of the building that depends on mass and stiffness of structural elements is determined using lumped mass modeling. Inherent damping is assumed to be Rayleigh type (i.e., proportional). Damping matrix is determined considering damping of 5 % critical damping for first and second mode. The building is subjected to two strong earthquake ground motions, El Centro and Loma Prieta earthquake and two pulse type earthquake ground motions, Kobe and Northridge earthquake.

Lumped mass model of the building shown in Fig. 7 along with passive device placed at ground floor is depicted in Fig. 8. Dynamic equation of motion the lumped mass model is given later in the text. Two types of passive dampers, namely, viscous damper and visco-elastic (VE) damper are considered in the present paper. Shear model of the building with passive damper as shown in Fig. 8 are subjected to two strong and two pulse type earthquake ground motions as mentioned earlier.

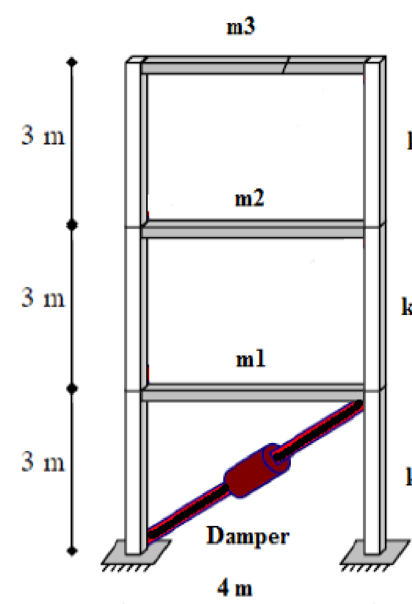

Fig. 8 BUILDING WITH PASSIVE DAMPER AT

GROUND FLOOR

The ground acceleration time history for El Centro, Kobe, Loma Prieta and Northridge is as shown in Fig. 9 below.

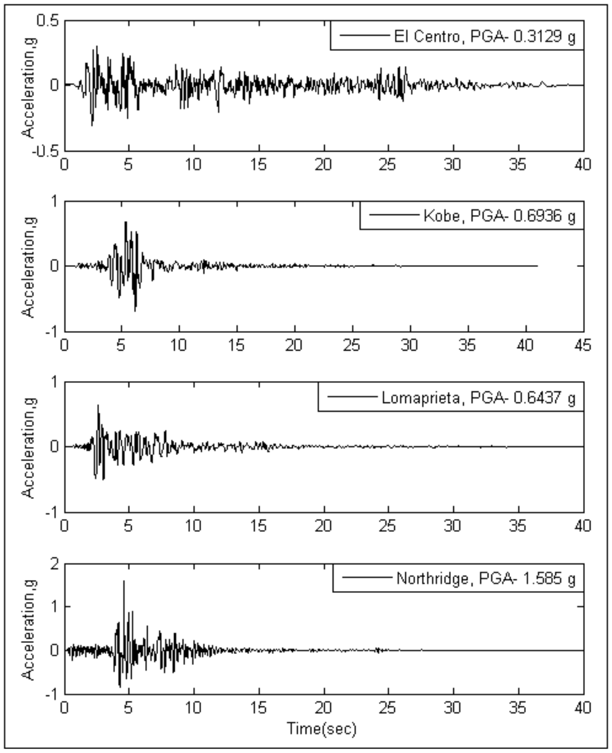

Fig. 9 GROUND ACCELERATION TIME HISTORY FOR VARIOUS TYPE OF EARTHQUAKES

Equation of motion for a three storey building subjected to earthquake ground motion is given by

$$M\ddot{x}(t) + C\dot{x}(t) + Kx(t) = -ML\ddot{x}_g \tag{9}$$

where, M is the mass matrix of size n × n, C is the damping matrix of size n × n, K is the stiffness matrix of size n × n, $x(t) = [x_1 \quad x_2 \quad x_3]^T$ is the relative displacement vector of the building , $L = [1 \quad 1 \quad 1]^T$ is the influence matrix for the excitation to the building and $\ddot{x}_g$ is the ground acceleration.

For a shear building with added passive dampers subjected to earthquake excitation, the equation of motion of the system combining building and dampers is given as,

$$M\ddot{x}(t) + C\dot{x}(t) + Kx(t) = -ML\ddot{x}_g - BF(t) \tag{10}$$

where, B is matrix derived based on placement of the passive devices in the building, $F = [F_1 \quad F_2 \quad F_3 \cdots F_n]^T$ is the vector of control forces produced due to dampers, here n is the number of storey of the building.

The control force F for linear viscous fluid dampers with damping co-efficient given by Eq. (2) when substituted in Eq. (10), one gets equation of motion for building with viscous damper subjected to earthquake excitation. This is expressed as,

(11)

Equation of motion for building with VE damper subjected to earthquake excitation is derived substituting Eq. (5) in Eq. (10) as

(12)

Analytical solution of Eq. (11) and Eq. (12) is not possible, since ground acceleration (i.e. earthquake excitation) varies arbitrarily with time. The solution needs numerical time steeping methods of integration. Many numerical integration methods are available.

The well known Newmark Beta direct integration method is quite often used to compute the structural response. This is based on the assumption that acceleration ($\ddot{x}$) varies linearly between two instants of time (i.e., Δt apart). Two parameter α and β are used in this method, which can be suit the requirement of the particular problem. Newmark [9] presented a family of time-step methods for the solution of structural dynamics problem for both blast and seismic loading. Newmark developed a family of time-stepping methods based on the following equations [9,10]

$$\dot{x}_{t+1} = \dot{x}_t + [(1-\gamma)\Delta t]\ddot{x}_t + (\gamma\Delta t)\ddot{x}_{t+1} \tag{13}$$

$$x_{t+1} = x_t + (\Delta t)\dot{x}_t + [(0.5-\beta)(\Delta t)^2]\ddot{x}_t + [\beta(\Delta t)^2]\ddot{x}_{t+1} \tag{14}$$

Newmark used Eqs. (10), (13) and (14) iteratively for each time step, for each displacement DOF of the structural system. Parameters γ and β define the variation of acceleration over a time step and determine the stability and accuracy characteristics of the method. Typical selection for γ is $\frac{1}{2}$ and $\frac{1}{6} \le \beta \le \frac{1}{4}$ is satisfactory from all point of view, including that of accuracy. When $\gamma = \frac{1}{2}$ and $\beta = \frac{1}{6}$ Eqs. (13) and (14) corresponds to the linear acceleration method and same is corresponds to the constant acceleration method when $\gamma = \frac{1}{2}$ and $\beta = \frac{1}{4}$.

V. RESULTS AND DISCUSSION

Firstly, response quantities of uncontrolled shear building under four types of earthquake excitations, i.e., El Centro, Kobe, Loma Prieta and Northridge, are obtained. These are obtained by solving Eq. (10) using Newmark Beta method with constant acceleration through writing code in MATLAB. Table 2 shows peak (i.e. maximum) response quantities (interstorey drift, displacement, velocity, acceleration) obtained for uncontrolled building under all the earthquake excitations considered.

TABLE II
RESPONSE QUANTITIES FOR UNCONTROLLED BUILDING

Response Quantity		El Centro	Kobe	Loma Prieta	North-ridge
Drift (m)	1	0.0105	0.0308	0.0288	0.0439
	2	0.0083	0.0238	0.0232	0.0344

	3	0.0047	0.0118	0.0117	0.0171
Displ. (m)	1	0.0105	0.0308	0.0288	0.0439
	2	0.0184	0.0455	0.0509	0.0784
	3	0.0228	0.0553	0.0625	0.0955
Velo. (m/s)	1	0.1965	0.422	0.553	0.770
	2	0.3266	0.692	1.007	1.508
	3	0.3858	0.792	1.251	1.904
Accel. (m/s^2)	1	5.476	9.673	10.279	16.318
	2	7.107	14.623	16.791	25.418
	3	8.382	17.823	21.119	31.330

It is evident from Table 2 that peak displacement, peak velocity and peak acceleration occurs at top storey of the building, however interstorey drift occurs at first storey for all the earthquake excitations. It is clearly seen from Table 2 that all response quantity is least for El Centro earthquake excitation but highest for Northridge earthquake excitation.

Table 3 shows peak response quantity extracted for shear building with viscous damper under four different types of earthquake excitation. The value of damping co-efficient (C_d) 50 kN.sec/cm is considered in order to obtain damper force using Eq. (2).

TABLE III
RESPONSE QUANTITIES FOR CONTROLLED BUILDING WITH VISCOUS DAMPER

Response Quantity		El Centro	Kobe	Loma Prieta	North-ridge
Drift (m)	1	0.0061	0.0153	0.0159	0.0198
	2	0.0056	0.0135	0.0150	0.0205
	3	0.0031	0.0068	0.0073	0.0113
Displ. (m)	1	0.0061	0.0153	0.0159	0.0198
	2	0.0107	0.0275	0.0300	0.0377
	3	0.0128	0.0342	0.0373	0.0489
Velo. (m/s)	1	0.0982	0.200	0.247	0.376
	2	0.2076	0.392	0.481	0.773
	3	0.2825	0.526	0.619	0.959
Accel. (m/s^2)	1	2.37	6.680	7.393	10.999
	2	5.938	9.900	11.329	13.446
	3	7.285	12.434	13.411	21.244
Damper Force (kN)		491.12	1002	1232.68	1881.08

It is evident from Table 3 that viscous damper is quite effective in controlling structural response of shear building. Reduction in peak interstorey drift at first, second and third storey is 41.9%, 32.5% and 34%, respectively, as compared to uncontrolled response under El Centro excitation. Similarly, reduction in peak interstorey drift under Kobe, Loma Prieta and Northridge earthquake excitations are 50.3%, 43.3%, 42.4%, 44.8%, 35.3%, 37.6%, and 54.9%, 40.4%, 33.9%, respectively, across all the stories. Thus, it is clear that addition of viscous damper reduces peak interstorey drift up to 50.3% for pulse type of earthquake excitation like Kobe. Peak displacement response also shows similar reduction for controlled building with respect to uncontrolled building under El Centro earthquake excitation. Reduction is 41.9%, 41.8% and 43.8% at first, second and third storey of controlled building, respectively. Under Kobe, Loma Prieta and Northridge earthquake reductions observed are 50.3%, 39.6%, 38.2%, 44.8%, 41.1%, 40.3% and 54.9%, 51.9%, 48.8% across all the stories of controlled building as compared to uncontrolled response.

Peak velocity response also shows reduction of similar order that of peak drift and displacement. For El Centro earthquake reduction in peak velocity is 50%, 36.4% and 26.8% for first, second and third storey, respectively. Similarly, reduction in peak velocity for Kobe, Loma Prieta and Northridge earthquakes are 52.6%, 43.4%, 33.6%, 55.3%, 52.2%, 50.5% and 51.2%, 48.7%, 49.6%, across all the stories for controlled building as compared to uncontrolled response. Peak acceleration response of controlled building shows less reduction compared to other response quantities. For all types of earthquake considered, reduction in peak acceleration are 56.7%, 16.5%, 13.1%, 30.9%, 32.3%, 30.2%, 28.1%, 32.5%, 36.5%, and 32.6%, 47.1%, 32.2% across all the stories compared to uncontrolled response. It is clear form Table 3 that damper force is least for El Centro earthquake excitation while it is highest for Northridge earthquake excitation.

In order to prove the effectiveness of viscous damper time history plots for all response quantities of controlled building were extracted. Fig. 10 and Fig. 11 shows time history plot of response quantity displacement, velocity and acceleration for controlled building under El Centro and Kobe earthquake, respectively.

Table 4 shows response quantities for controlled building with viscoelastic damper of dimension 0.65 m × 0.25 m × 0.016 m designed according to Hanson & Soong [11] to obtained damping ratio (ξ) of 16%. For the given dimension and target damping ratio, damping co-efficient (C_d) and lateral stiffness (K_d) derived are 2815.06 KN.Sec/m and 42.01 MN/m, respectively.

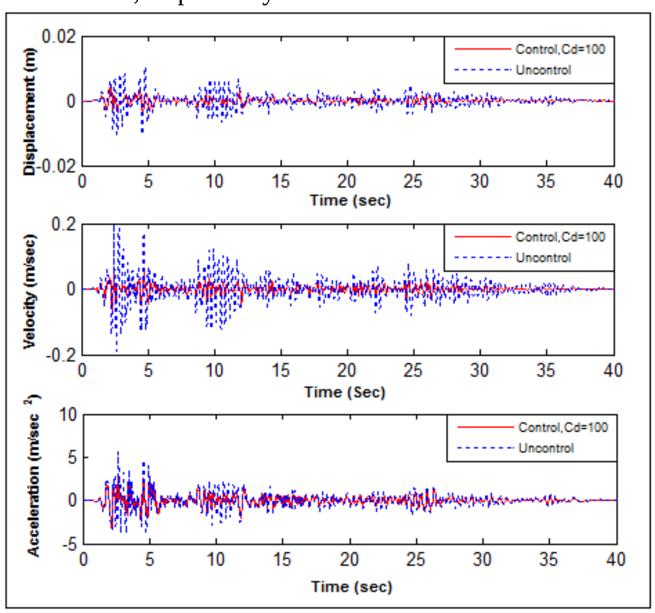

Fig. 10 TIME HISTORY RESPONSE AT FIRST STOREY UNDER EL CENTRO EARTHQUAKE EXCITATION

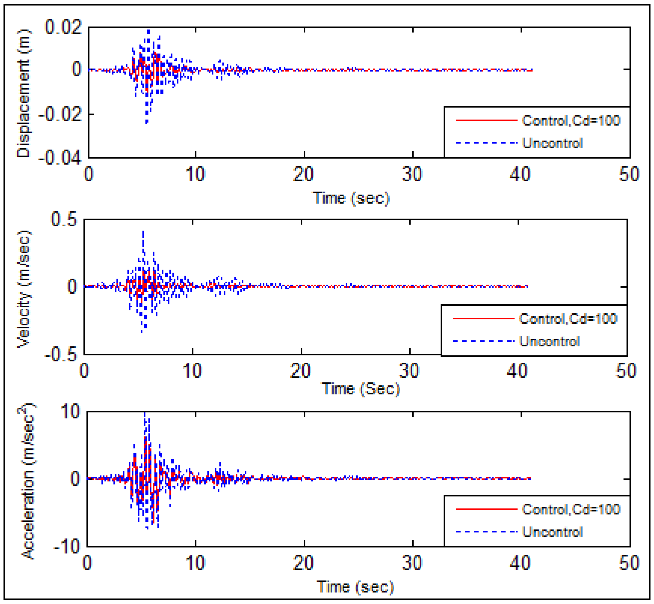

Fig. 11 TIME HISTORY RESPONSE AT FIRST STOREY UNDER KOBE EARTHQUAKE EXCITATION

TABLE IV
RESPONSE QUANTITIES FOR CONTROLLED BUILDING WITH VISCOELASTIC DAMPER

Response Quantity		El Centro	Kobe	Loma Prieta	North-ridge
Drift (m)	1	0.00583	0.0141	0.0124	0.01184
	2	0.00644	0.0150	0.01188	0.01541
	3	0.00349	0.00745	0.00567	0.01081
Displ. (m)	1	0.0058	0.0141	0.0124	0.0118
	2	0.0117	0.0290	0.02415	0.0255
	3	0.0149	0.0364	0.02979	0.0363
Velo. (m/s)	1	0.1174	0.208	0.136	0.292
	2	0.2354	0.446	0.266	0.673
	3	0.2984	0.572	0.325	0.842
Accel. (m/s^2)	1	3.950	8.158	7.544	7.856
	2	5.105	11.246	9.049	10.144
	3	6.476	13.457	10.296	19.563
Damper Force (kN)		383.83	827.44	636.73	819.05

It is evident from Table 4 that all response quantities show reduction when viscoelastic damper is attached to the building. Reduction in interstorey drift of the building under El Centro earthquake excitation is found to be 44.5%, 22.4% and 25.7% for first, second and third storey, respectively. Reduction in interstorey drift of the building is of higher order as compared to El Centro earthquake under Kobe, Loma Prieta and Northridge earthquake excitations, i.e., 54.2%, 37%, 36.9%, 56.9%, 48.8%, 51.5% and 73%, 55.2%, 36.8%, respectively, across all the stories.

Response quantities like Displacement and Velocity also show reduction for controlled building as compared to uncontrolled building. Reduction in displacement response are 44.8%, 36.4%, 34.7%, 54.2%, 36.3%, 29.8%, 56.6%, 52.6%, 52.3%, 73.1%, 67.5% and 62%, respectively, for all the stories, for all four types of earthquake excitation. Similarly, reduction in velocity response are 40.3%, 28%, 22.7%, 50.7%, 35.6%, 27.8%, 75.4%, 73.6%, 74%, 62.1%, 55.4% and 55.8%, respectively, for all the stories under all types of earthquake excitations considered.

However, reduction in acceleration response is quite less as compared to displacement/velocity response. Reduction in acceleration response are 27.9%, 28.2%, 22.7%, 15.7%, 23.1%, 24.5%, 26.6%, 46.1%, 51.3%, 51.9%, 60.1% and 37.6%, respectively, for all the stories under all types of earthquake excitations considered. It is observed that force demand from a VE damper, due to four earthquake excitation, is moderate. Damper force is least, i.e., 383.8 kN, for a El Centro earthquake while it is highest, i.e., 827.4 kN for a Kobe earthquake.

It is evident from results obtained and as discussed above that both Viscous and VE damper is quite effective in controlling seismic response of the building under consideration. It is also clear that damper forces demanded by all the earthquake excitation are practically realizable.

VI. CONCLUSION

A three storey shear building with Viscous and VE damper subjected to four earthquake excitations (El Centro, Kobe, Loma Prieta, Northridge) is considered and solved using numerical method Newmark – Beta through MATLAB. Response quantities like Displacement, Velocity, Acceleration, Interstorey Drift and Damper force are extracted. It is found that both Viscous and VE damper are quite effective in controlling the response of the building under all the earthquake excitations considered. Reduction in interstorey drift ranges between 32% to 54%, displacement between 38% to 58%, velocity between 27% to 55% and acceleration between 13% to 56% for building with viscous damper under four type of earthquake excitations.

Building with VE damper subjected to various earthquake excitations shows reduction in interstorey drift ranges between 22% to 73%, Displacement 30% to 73%, Velocity between 23% to 75% and acceleration between 15% to 51%.Damper force ranges between 383.83 kN to 1881.08 kN for Viscous and VE damper under various earthquake excitations.

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