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Vibration Control of Building Using Base Isolation Under Near Fault Earthquakes

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Abstract
The seismic response of a single-story symmetric building with laminated rubber bearing(LRB) is investigated. The comparative performance of laminated rubber bearing isolation investigated for single storey symmetric building under selected past earthquake ground motions. The seismic response is obtained by numerically solving the governing equations of motion using the state-space solution. The behavior of LRB and fixed base structure is studied through various response parameters such as floor acceleration, floor relative displacement, mass ratio, isolator displacement, and isolator force. It is observed that the LRB base isolated system is quite effective in reducing various seismic responses.

Keywords — *Symmetric Building, Seismic Response, Optimum, Base isolation, Near fault earthquake*

I. INTRODUCTION

Seismic isolation has emerged as a potential strategy in preventing damages to the buildings and sensitive equipment housed within them during severe earthquakes. The basic concept of isolation is to detach the building from the ground, instead of the conventional techniques of strengthening the structural members. The isolation devices essentially have two important roles to play: providing horizontal flexibility and serve as an energy dissipation mechanism. The flexibility of the isolation system results in the lengthening of the fundamental period of the building, shifting it away from the region of dominant earthquake frequency contents, whereas the energy absorbing capacity increases due to the isolation damping. The seismic base isolation systems are mainly classified as sliding systems (friction pendulum) and elastomeric isolation system (rubber bearing). These are the systems that combine simplicity, reliability, and economy. The laminated rubber bearing (LRB) base isolation system, is the most common system, consisting of alternate layers of rubber and steel plates. To achieve damping and initial rigidity a lead core is inserted in the lead–rubber bearings which are widely used in New Zealand The severity of impact in the case of base-isolated buildings and the comparative performance of various isolation systems have been studied by Matsagar and Jangid(2003) for a shear model of the structure, dealing with two-dimensional (2D)idealization, were in the impact considered was in the normal direction(not oblique)as no rotational degrees-of-freedom were considered.[3]. When the structure is torsionally coupled due to dissimilarity of the different bearing parameters or the system properties, strong coupling of responses in the three principal directions may occur when the torsional frequency is closer to the two lateral frequencies. Such torsional coupling occurs, especially in the case of base-isolated structures, if the eccentricity between the center of mass (CM) and the center of rigidity (CR) exists at the superstructure and/or the isolation levels (Matsagar and Jangid,2005) [2]. The impact response of the torsionally coupled base-isolated structure with lead rubber bearing, HDRB, and FPS isolation system was studied by Matsagar and Jangid (2008) [7].

Kulkarni and Jangid study the response of a rigid body of base-isolated structure with different isolation systems. [1] Jangid and Kelly study the parameter of base isolation for near-fault earthquake motion. [4] Sharma and Jangid studied the behavior of high initial isolator systems on the base-isolated structure. [5]

In this paper, the study is carried out for vibration control of the building by the base isolation system of laminated rubber bearing (LRB) for a one-way symmetric building. The response of buildings investigated under different near-fault earthquake ground motions. The specific objectives are to study (i) the performance of the building under near-fault ground motion and (ii) the influence of variation in parameters of the base-isolated structures such as flexibility of the superstructure and isolator and damping.

II. MODELLING OF BASE ISOLATED STRUCTURE

The popularly used laminated rubber bearings (LRB) comprise steel and rubber plates built through a vulcanization process in the alternate layers. The dominant feature of LRB is the parallel action of the linear spring and damping. The LRB is characterized by high damping capacity, horizontal flexibility, and high vertical stiffness. A schematic diagram of the LRB is shown in figure 1(c), which represents the linear stiffness with viscous damping for bi-directional excitation. It is to be noted that such an equivalent linear model of an isolation system is quite simple and generally accurately predicts the results except for a few typical isolator parameters. [2] The force-deformation relationship of isolation is shown in figure 1(b). Figure 1(a) represents the elevation of the symmetric building.

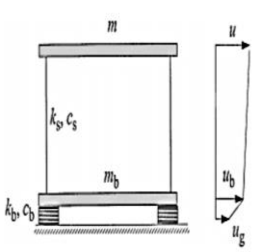

Fig. 1(a)

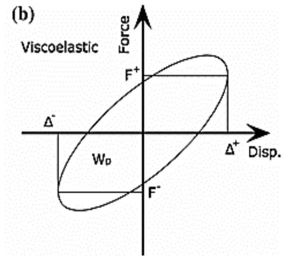

Fig. 1(b)

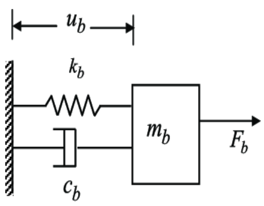

Fig. 1(c)

Figure 1 Schematic diagram of the LRB base-isolated building

The restoring force (F_b) developed in the LRB is given by equation (1),

$$F_b = c_b\dot{x}_b + k_b x_b \tag{1}$$

Where c_b and k_b are the damping and stiffness of an isolator respectively. The stiffness and damping of the LRB is selected to provide the specific values of the two parameters namely the isolation period (T_b) and damping ratio (ξ_b) defined in equation (2) and (3)

$$T_b = 2\pi\sqrt{\frac{m_b + \sum_{j=1}^{N} m_j}{k_b}}$$

$$\xi_b = \frac{}{2(m_b + \sum_{j=1}^{N} m_j)\,\omega_b}$$

where, $\omega_b = 2\pi/T_b$. (2)

III. SOLUTION OF EQUATIONS OF MOTION

The base-isolated system is excited by a single horizontal component of earthquake ground motion. At each floor and base mass, one lateral dynamic degree-of-freedom is considered. The governing equations of motion for the fixed-base one-story superstructure model is expressed in matrix form as equation (4).

$$M^*\ddot{V} + C\dot{V} + KV = -M^* r\ddot{u}_g \tag{4}$$

The mass matrix M^* can be expressed as shown in equation (5), where m represents the lumped mass of the superstructure; m_b represents the base mass of the isolation system. And υ is the vector of relative displacement.

$$M^* = \begin{pmatrix} M & m \\ m & m \end{pmatrix} \tag{5}$$

Where, $M = m_b + m_s$. The damping matrix expressed as equation (6),

$$C \quad \begin{pmatrix} c_b & 0 \\ 0 & c_s \end{pmatrix} = \tag{6}$$

Where c_s is the damping of the superstructure. The stiffness matrix K can be expressed as equation (7). Where k_s is the stiffness of the superstructure.

$$K = \begin{pmatrix} k_b & 0 \\ 0 & k_s \end{pmatrix} \tag{7}$$

The governing equations of motion are solved using the state space method and it is written in equation (8), where $Z = \{\upsilon, \acute{\upsilon}\}$, and $\dot{Z} = \{\acute{\upsilon}, \ddot{\upsilon}\}$are state vectors; A is the system matrix, and E is the distribution matrix of excitation which is $[0\ r]^T$. These matrices are expressed as shown in equation (9), where, I am the identity matrix and $\ddot{u}_g$ is ground acceleration.

$$\dot{Z} = A\,Z + E\,\ddot{u}_g \quad \text{and} \quad Z = A_d\,Z + E_d\ddot{u}_g \tag{8}$$

$$A = \begin{pmatrix} 0 & I \\ -M^{-1}K & -M^{-1}C \end{pmatrix} \tag{9}$$

Where $A_d = e^{A\Delta t}$ represent the discrete-time step system matrix with Δt as a time interval. The constant-coefficient matrices E_d are discrete-time counterparts of matrices of E and can be written as shown in equation (10).

$$E_d = A^{-1}(A_d - I)\,E \tag{10}$$

IV. NUMERICAL STUDY

Seismic response of symmetric building with LRB isolated building investigated by numerical simulation using MATLAB. Parameters of building and isolator are taken as follow:

- Size of beam: 230 mm x 460 mm

- Size of the column: 300 mm x 300 mm
- The thickness of slab: 100 mm
- Floor finish: 1 kN/m^2
- Live load: 2.5 kN/m^2
- The period of structure (T_s): 0.5 and 1.5 Sec
- The damping ratio of structure (ξ_s): 5%
- The period of Isolator (T_b): 1 sec to 3 Sec (with a 0.5-sec difference)
- Damping ratio of isolator (ξ_b): 5% to 30% (with 5% difference)
- Grade of concrete: M20

The analysis has been carried out using six different near-fault earthquake ground motions. Details of a near-fault earthquake are shown in Table1. The earthquake time histories are shown in figure (2).

Table I
Property of earthquake ground motion

Earthquake	Recording station	PGA (g)
Imperial Valley, October 15, 1979	Array #5	0.36
Imperial Valley, October 15, 1979	Array #7	0.45
Northridge, January 17, 1994	Newhall	0.70
Landers, June 28, 1992	Lucerne Valley	0.71
Northridge, January 17, 1994	Rinaldi	0.87
Northridge, January 17, 1994	Sylmar	0.72

The following procedure is adopted to obtain the optimum values for T_b and ξ_b.

Step:1 Find the maximum absolute value of displacement and acceleration for all selected earthquake ground motion and selected range of isolator parameter (T_b and ξ_b) by solving the equation of motion numerically.
Step:2 Take the average of all maximum absolute value of displacement and acceleration for all earthquake ground motion.
Step:3 Also, do these steps for the fixed base structure and find average maximum absolute values for all selected earthquake motion.
Step:4 Find factor R

$$R = \frac{\text{Average Maximum absolute value of the isolated base structure}}{\text{Average Maximum absolute value of the fixed base structure}}$$

Find R factor for displacement and acceleration.
Step:5 Plot displacement and acceleration graph for damping ratio of the isolator, factor R, and Period of the isolator.
Step:6 From the above step select the optimum value of damping ratio and period of the isolator. Using these values find the optimum value of m_b/m ratio ranges from 0.1 to 2 with 0.1 difference.
Hereafter optimization values are selected as, $T_b = 3$ sec and ξ_b = 15% and m_b/m ratio taken as 1 from figure (3).

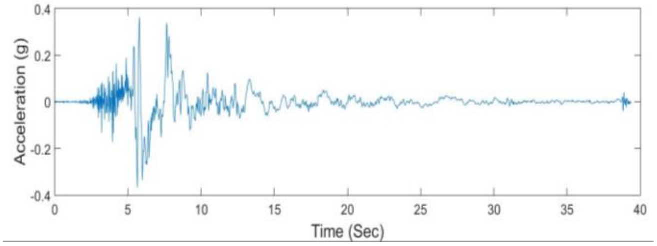

Fig. 2(a) Imperial valley (Array #5)

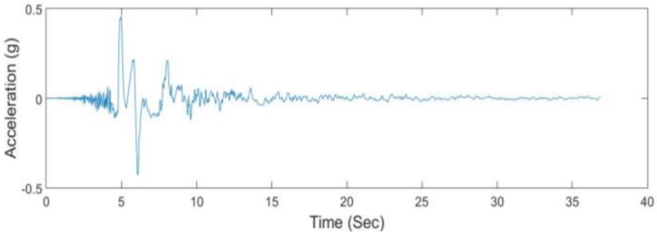

Fig. 2(b) Imperial valley (Array #7)

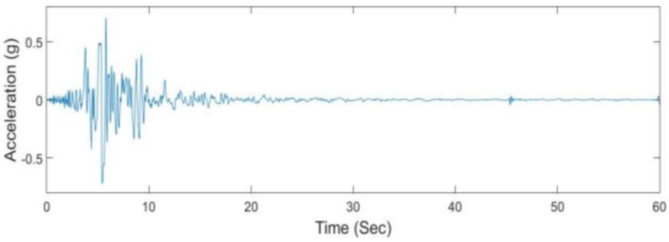

Fig. 2(c) Northridge (Newhall)

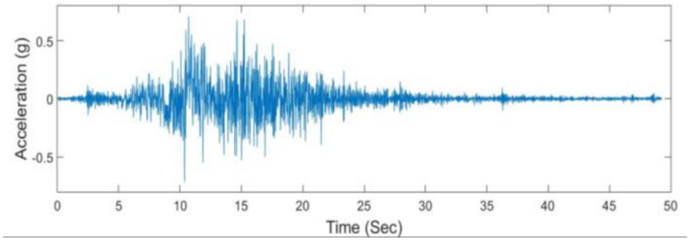

Fig. 2(d) Landers (Lucrene valley)

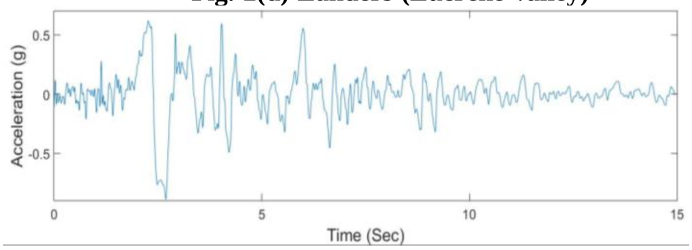

Fig. 2(e) Northridge (Rinaldi)

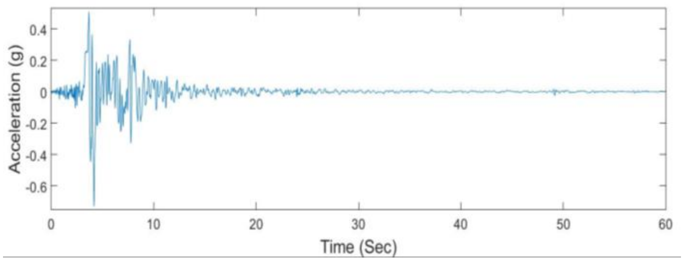

Fig. 2(f) Northridge (Sylmar)
Figure 2 Near fault Earthquake ground motions

Figure (3) shows the optimized values for the isolated base structure. As shown in figure 3(a) for relative displacement, the R ratio becomes constant after damping of the isolator is 15% and minimum when the period of the isolator is 3 Sec.

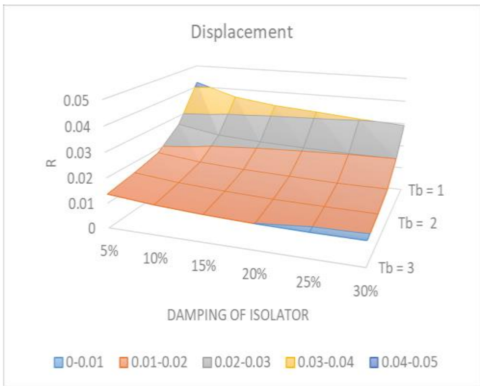

Fig. 3(a)

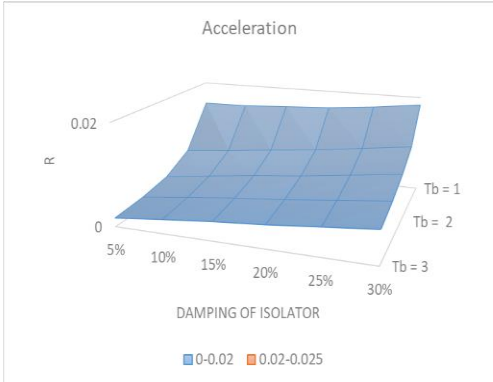

Fig. 3(b)

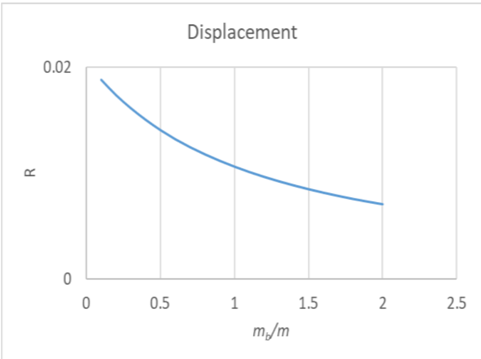

Fig. 3(c)

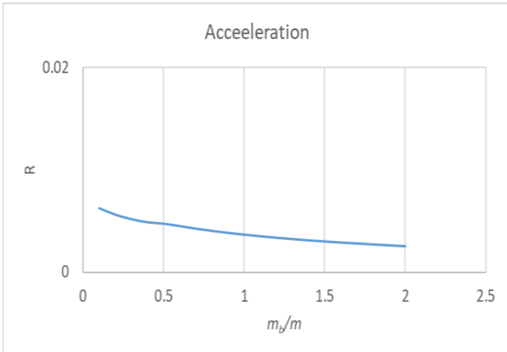

Fig. 3(d)

Figure 3 Various plot for R factor for $T_s = 0.5$ Sec

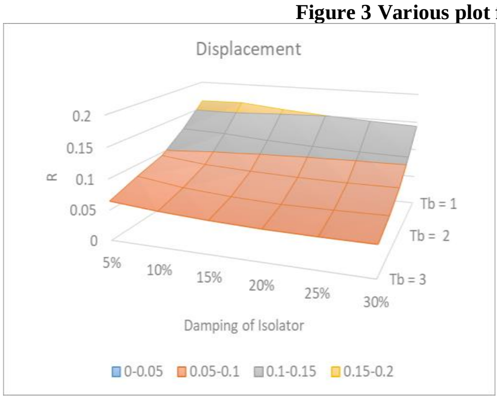

Fig. 4(a)

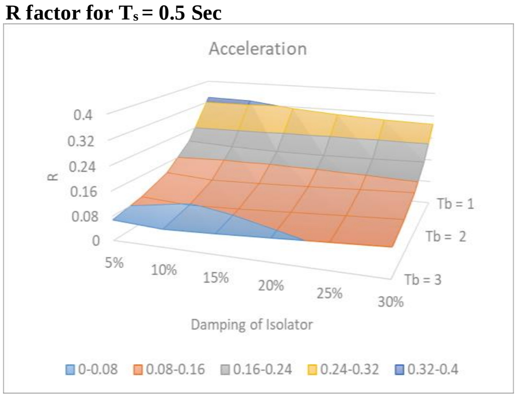

Fig. 4(b)

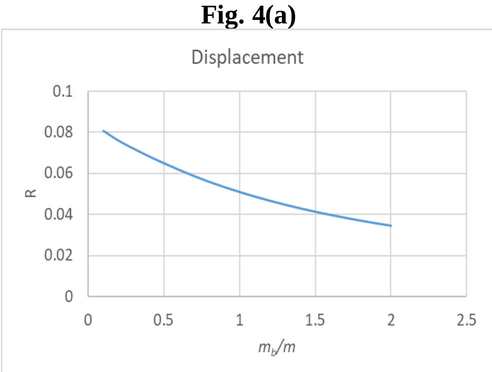

Fig. 4(c)

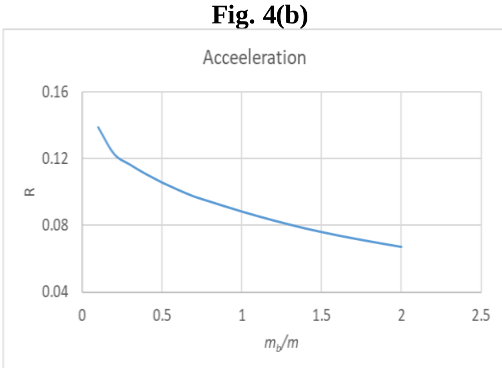

Fig. 4(d)

Figure 4 Various plot for R factor for $T_s = 1.5$ Sec

Fig. 4(a) and 4(b) shows the relative displacement and acceleration plot for the R factor vs the period of isolator and damping of the isolator. From that, it can be said that the optimum value for some time of the isolator is 3 Sec and the damping of an isolator is 15%. Fig. 4(c) and 4(d) shows the optimum value for mass ratio (*mb/m*) is 1.

After deciding the optimum parameters for isolator analysis carried by solving the equation of motion. And results are compared for the fixed base and isolated base structure in terms of relative displacement, acceleration. The isolator vs isolator displacement indicates the dissipation of energy.

Here, the results are shown for the Imperial valley (Array#5, October 15, 1979) and Northridge (Sylmar, January 17, 1994).

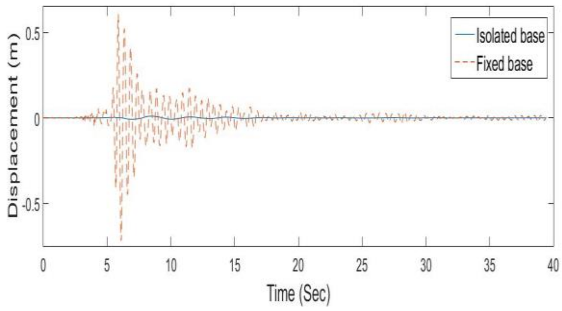

Fig. 5(a) Displacement time history

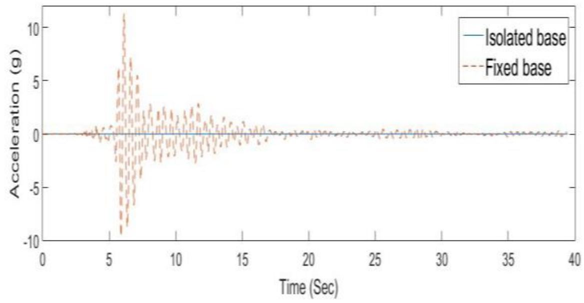

Fig. 5(b) Acceleration time history

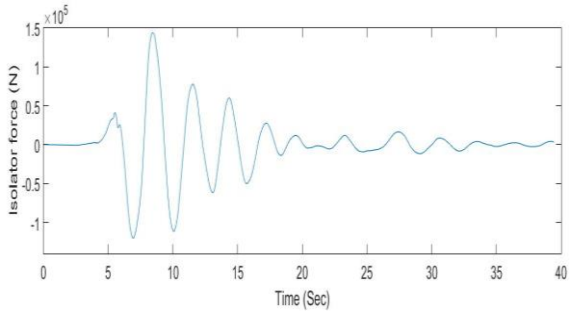

Fig. 5(c) Isolator force

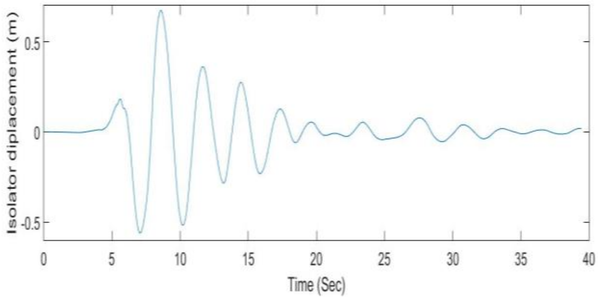

Fig. 5(d) Isolator displacement

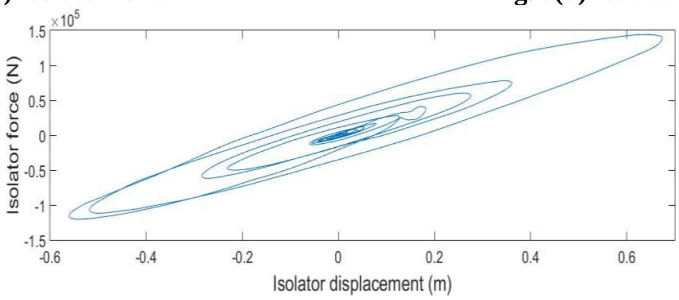

Fig. 5(e) Hysteresis loop of LRB

Figure 5 Results for Imperial valley (Array #5) for T_s = 0.5 Sec

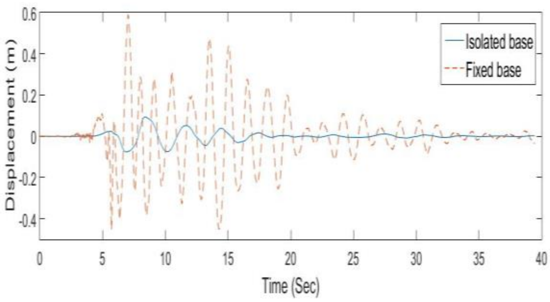

Fig. 6(a) Displacement time history

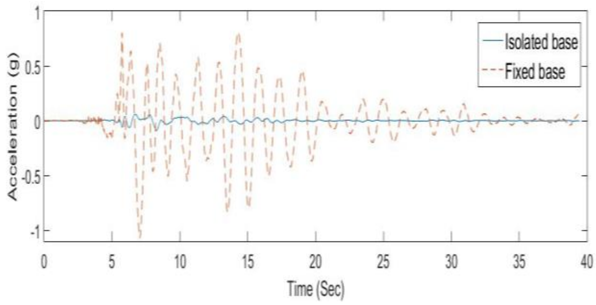

Fig. 6(b) Acceleration time history

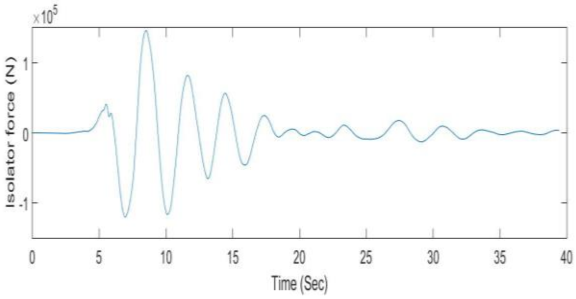

Fig. 6(c) Isolator force

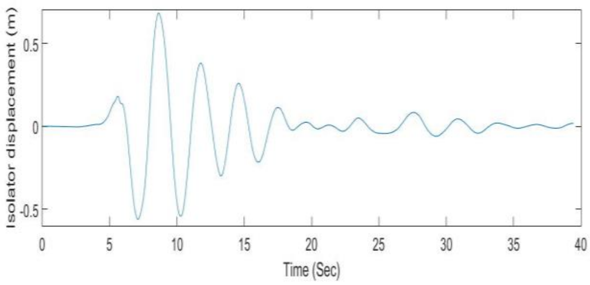

Fig. 6(d) Isolator displacement

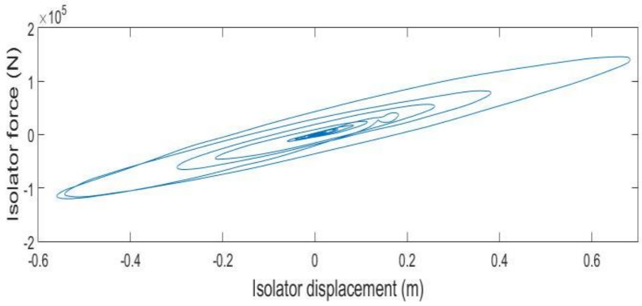

Fig. 6(e) Hysteresis loop of LRB

Figure 6 Results for Imperial valley (Array #5) for Ts = 1.5 Sec

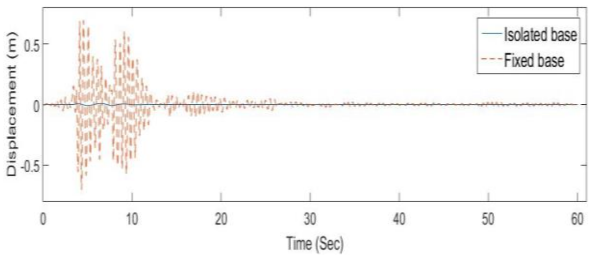

Fig. 7(a) Displacement time history

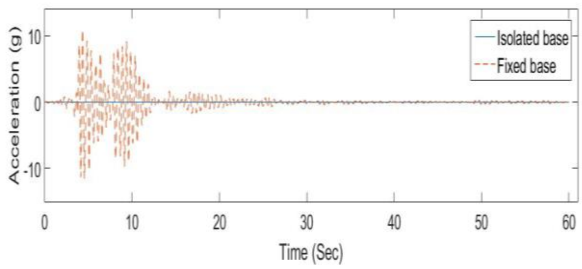

Fig. 7(b) Acceleration time history

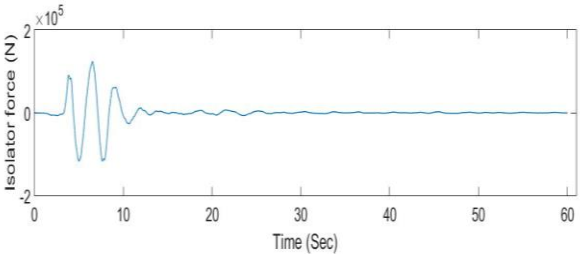

Fig. 7(c) Isolator force

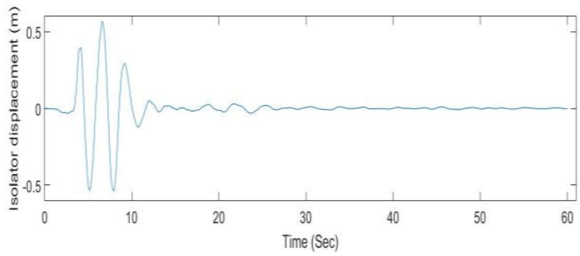

Fig. 7(d) Isolator displacement

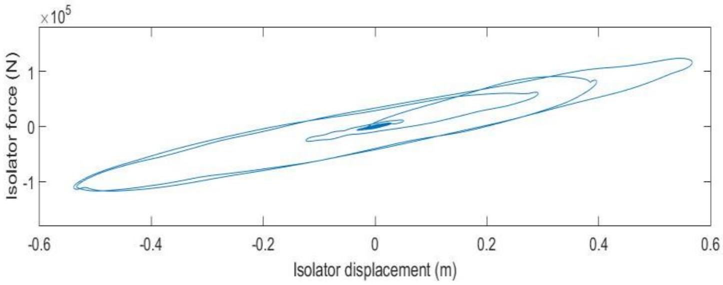

Fig. 7(e) Hysteresis loop of LRB

Figure 7 Results for Northridge (Sylmar) for Ts = 0.5 Sec

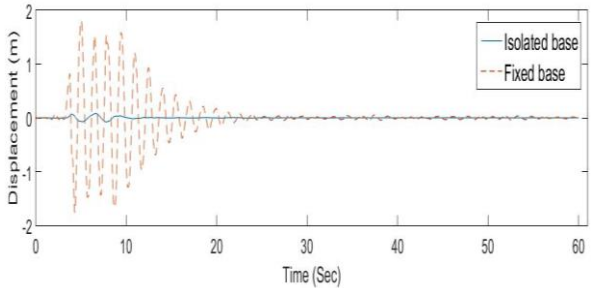

Fig. 8(a) Displacement time history

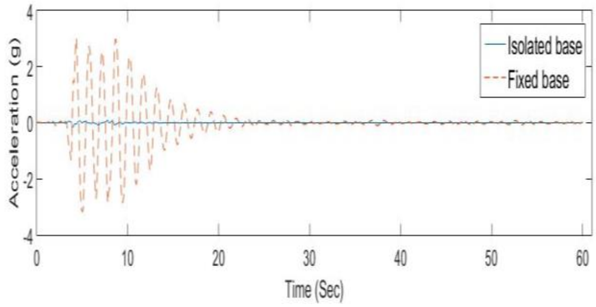

Fig. 8(b) Acceleration time history

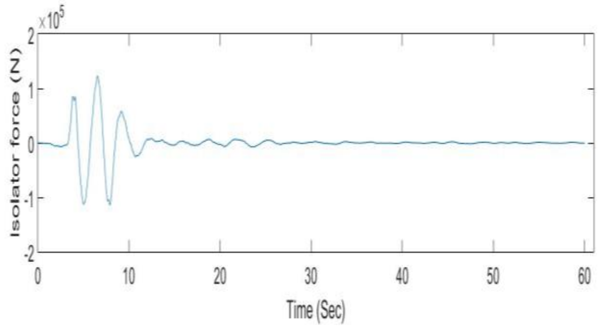

Fig. 8(c) Isolator force

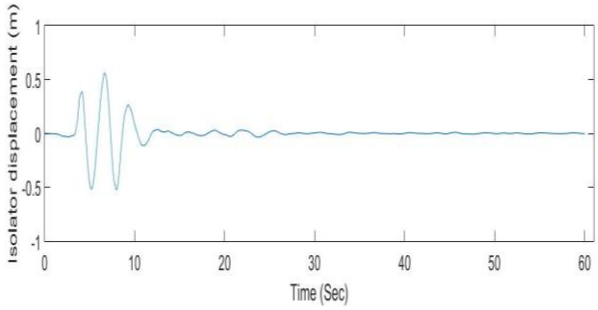

Fig. 8(d) Isolator displacement

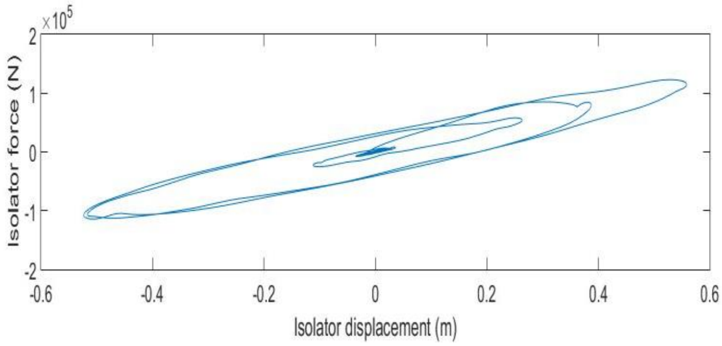

Fig. 8(e) Hysteresis loop of LRB
Figure 8 Results for Northridge (Sylmar) for Ts = 1.5 Sec

Table II represents a summary for reduction of relative displacement and acceleration for all six earthquake ground motions which is taken for some time of the structure as 0.5 Sec. Table III represents the period of the structure at 1.5 Sec.

Table II
Comparison of results for Ts = 0.5 S

Type	**Criteria**	**Imperial Valley (Array #5)**	**Imperial Valley (Array #7)**	**Northridge (Newhall)**	**Landers (Lucerne)**	**Northridge (Rinaldi)**	**Northridge (Sylmar)**
Fixed base	Displacement (m)	0.7194	0.5534	1.3766	0.4087	0.9983	0.7048
Isolated base		0.0098	0.0084	0.0052	0.0091	0.0092	0.0087
Fixed base	Acceleration (g)	11.3046	8.9923	22.3761	6.6633	16.1500	11.5508
Isolated base		0.0264	0.021	0.0697	0.0388	0.0593	0.0527

Table III
Comparison of results for Ts = 1.5 S

Type	Criteria	Imperial Valley (Array #5)	Imperial Valley (Array #7)	Northridge (Newhall)	Landers (Lucerne)	Northridge (Rinaldi)	Northridge (Sylmar)
Fixed base	Displacement (m)	0.5900	1.0714	2.2529	0.9951	2.7633	1.8013
Isolated base		0.0940	0.0865	0.0695	0.0808	0.0952	0.0801
Fixed base	Acceleration (g)	1.0701	1.8860	3.8732	1.7865	4.9753	3.1728
Isolated base		0.0888	0.1789	0.2732	0.0811	0.3084	0.1664

V. CONCLUSIONS

The seismic response of single-story symmetric LRB base-isolated building with different near-fault earthquake ground motion is investigated. From the present numerical study, the following conclusions can be made,

1. LRB base isolation is effective in reducing relative displacement as well as acceleration under near-fault ground motion compared with a fixed base.
2. The reduction in various response depends on isolator damping, isolator period as well as characteristics of earthquakes.
3. It is believed that reduction is higher as compared to the structure with a period of 1.5 Sec.
4. There exists an optimum value of isolator damping, isolator period, and mass ratio.

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