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RESEARCH ARTICLE OPEN ACCESS

Earthquake Performance of RC Buildings Using Elastomeric Base Isolation Controls

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ABSTRACT

The devastation from earthquakes becomes unpredicted resulting to significant damage of civil structures, leads to loss of lives and property. The base isolation of passive control system is one of the most powerful techniques for protection of civil structures against to seismic hazard. The study in this paper has proposed two seismic controls, namely LRB control and NZ control to study the seismic performance of isolated RC building in terms of reduction in responses under four realistic unidirectional earthquakes. The computer codes have been generated in MATLAB 7® to analyze the building responses in which equations of motion are solved using Newmark's method whereas Wen's model is used to model the bearing force. The responses of isolated building are compared with responses of non-isolated building in terms of time varying displacement, acceleration in addition to peak response of displacement, acceleration and bearing displacement. The results of computer codes illustrate that both the proposed controls yields effective in reducing the responses of isolated building. Further, NZ control is relatively more effectively perform than LRB control in reducing the responses.

Keywords: Seismic performance, base isolation system, non-isolated building, isolated building, building responses; LRB control; NZ control

I. INTRODUCTION

The protection of civil structures against natural hazards becomes one of the challenges to an engineers and researchers as because experiences about hazards during recent past earthquakes. Moreover, to ensure the safety and comfort to the users during natural violence, one has to compel the engineers and scientists to think about innovative techniques and approaches to save the buildings and structures from the destructive forces of earthquakes. The aseismic design philosophy is one of the approaches to control over the earthquake hazard in which controlling devices works on various control techniques such as active, passive and semiactive or its combination [1]. In recent years, considerable attention has been paid for the development of structural control and become an important part of designing new structures to resists the hazardous forces. There have been significant efforts by researchers to investigate the possibilities of using various control methods to mitigate earthquake hazards. Among that one of the most popular as passive control system in which base isolation system is one the prominent control in reducing the structural responses of non-isolated building [2].

The passive controlling devices are activated by structural momentum or motion, therefore no external power supply to develop the counter or control forces but having limitation is, it cannot adapt to varying loading conditions. The main concept of isolation is to increase the fundamental time period of structural vibration beyond the energy containing periods of earthquake ground motion. Thus, passive systems may perform well in pre-described loading conditions for which they were designed but may not be effective in other situations [3].

The passive control devices may attenuate the vibrational energy due to earthquakes either by dissipation or isolation techniques. The passive control system in which base isolation is one of the prominent seismic controlling techniques which works by reflecting the seismic energy input rather than absorbing/dissipating as a result building get decouple from ground motion by deflecting bearing itself [4]. Further base isolation system is categorized into elastomeric base isolation and sliding base isolation. This study is concern to elastomeric base isolation which is further classified into elastomeric base isolation without and with central lead core. The elastomeric base isolation without central lead core is also called as laminated rubber bearing (LRB) whereas elastomeric base isolation with central lead core known as lead rubber bearing (NZ). The laminated rubber bearing (LRB) without central lead core is extensively used in practices under comparatively with low frequency input. The basic components of LRB system are steel and rubber plates built in alternate layers with rubber being vulcanized to the steel plates [5]. The NZ system is same as that of LRB system except central lead core which provides an additional means of energy dissipation. This type of bearing is widely used in New Zealand, hence sometimes referred as NZ system. Due to provision of lead core, energy recovery, re-crystallization and grain growth is continuously restoring the mechanical properties of lead core in addition to good fatigue properties during cyclic loading and is readily available at high purity [6].

absorbing capacity of lead core reduces the lateral deformation of isolation. Moreover, The process of

This study investigates the response reduction of RC building with two proposed controls. The first control in which building is isolated by laminated rubber bearing without central lead core, stated as LRB control whereas building isolated by lead rubber bearing, designated as NZ control. The objectives are (1) study the seismic performance of LRB control and NZ control In reducing the building responses (2) compare the reduction in peak responses of isolated building with the peak responses of non-isolated building (3) compare the reduction in peak value of bearing displacement under proposed during various earthquakes.

II. Structural Model

The structural model consists of 10 storied RC building of non-isolated and isolated with elastomeric bearing at the base of building foundation as shown in figure 1(a) and 1(b) respectively. The building model is idealized as a linear shear type with a lateral degrees-of-freedom at each floor levels including isolation floor. The structural building model is assumed to remain in linear elastic state, therefore, does not yield during excitation. It is also considered that building is subjected to only unidirectional excitation due to earthquakes. The system is assumed to remain in linear elastic state in addition to spatial variation of ground motion and also effect due to soil structure interaction is neglected.

The governing equations of motion for multi degrees-of-freedom structure are expressed in matrix form as:

$$[M]\{\ddot{u}\}+[C]\{\dot{u}\}+[K]\{u\}=-[M]\{r\}\ddot{u}_g+[B_p]\{f_b\} \tag{1}$$

where, $[M]$, $[C]$, and $[K]$ are the mass, damping and stiffness matrices of the building respectively, $\{u\}=\{u_b, u_1, u_2, u_3 \ldots\ldots u_N\}$, $\{\dot{u}\}$ and $\{\ddot{u}\}$ are the vectors of relative floor displacement, velocity and acceleration response respectively, $\ddot{u}_g$ is the ground acceleration due to earthquake, $\{r\}$ is the vector of influence coefficient having all elements equal to one, $[B_p]$ is the bearing location vector, $\{f_b\}$ is the vector of bearing force and (u_b) is the displacement of isolation floor with respect to the ground motion.

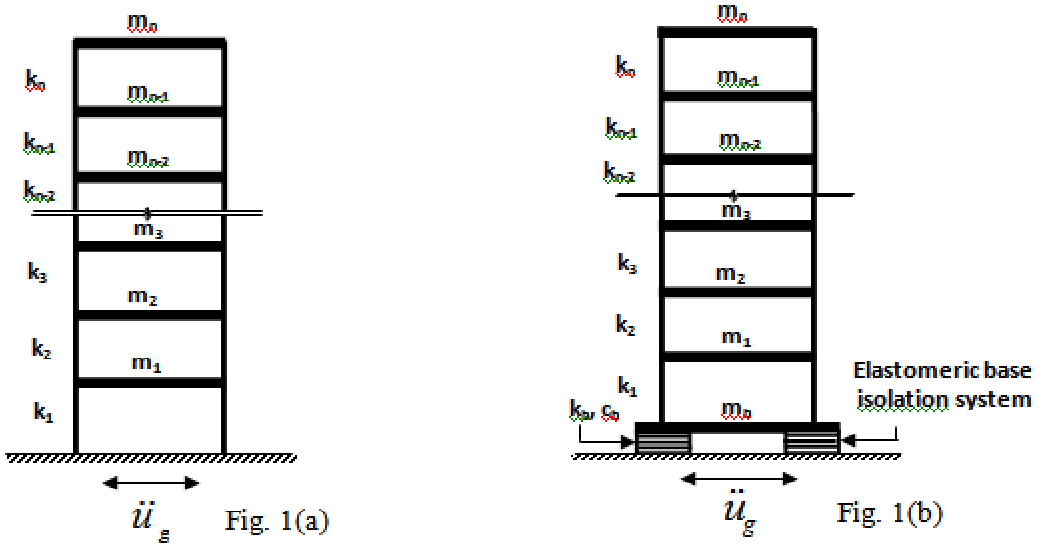

Fig. 1(a) Fig. 1(b)

Fig 1. Structural model of non-isolated and isolated RC building

2.1. Modeling of laminated rubber bearing

The elastomeric bearing without central lead core (LRB system) consisting of alternate layers of natural or synthetic rubber vulcanized between steel shims along with two thick end plates as shown in Figure 2 (a). The dominant feature of system is the parallel action of spring stiffness and viscous dashpot which is shown by schematic diagram in figure 2 (b).

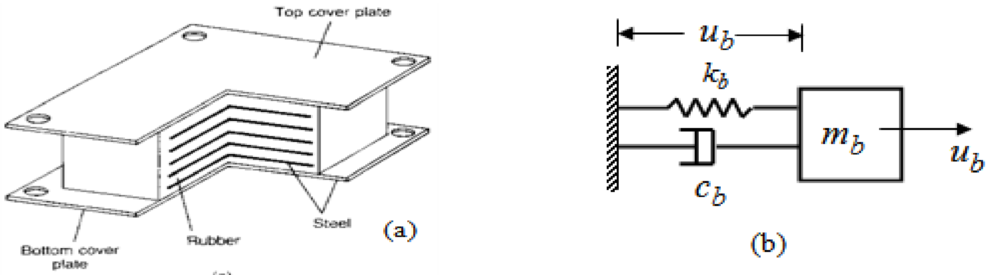

Fig 1. Cross section and schematic diagram of LRB system

The bearing force generated by this system is expressed as

$$f_b = c_b \dot{u}_b + k_b u_b \tag{2}$$

where k_b and c_b are the stiffness and damping parameters of LRB system respectively whereas $\dot{u}_b$ and u_b is the velocity and displacement of isolation floor, respectively.

2.2. Modeling of lead rubber bearing

The basic components of this bearing are similar to the components of LRB system except central lead core as shown in figure 3 (a). The presence of central lead provides an additional means of energy dissipation and reduces the lateral deformation of isolator [7]. The force-deformation behaviour of bearing has nonlinear characteristics and its hysteretic behaviour is described by Wen's model [9].

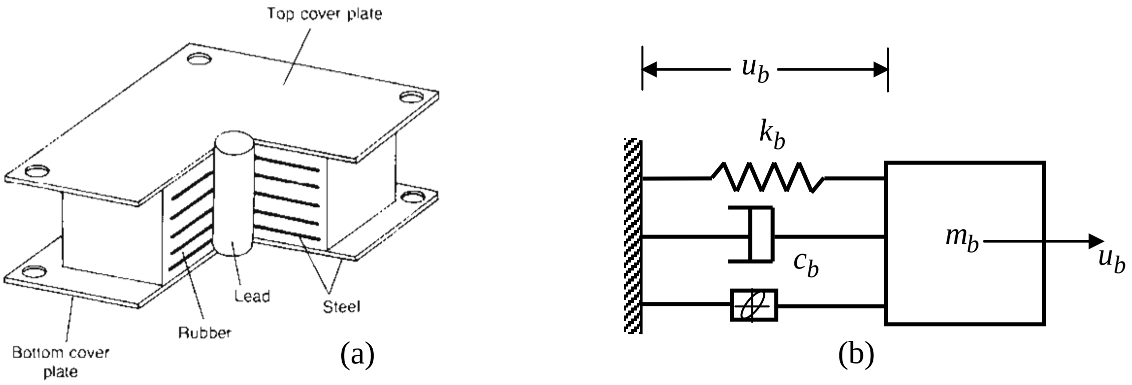

Fig. 3. Cross section and schematic diagram of lead rubber bearing (NZ system)

The yielding of bearing force by this system is given as

$$f_b = c_b \dot{u}_b + \alpha k_0 u_0 + f_z \tag{3}$$

where z is the hysteretic displacement evaluated by Wen's model [11], satisfying nonlinear first order differential equation as

$$f_z = (1-\alpha) F_y q z \tag{4}$$

$$q\dot{z} = -\beta |v_b| z |z|^{n-1} - \tau v_b |z|^n + A v_b \tag{5}$$

where, q is the yield displacement of bearing, β and τ are the strengthening coefficient due to presence of lead plug which controls the shape and size of hysteresis loop, n and A are the integer constants which controls the smoothness of transition from elastic to plastic state. These parameters β, τ, n and A are selected so as to provide a rigid-plastic shape (typical Coulomb-friction behavior).

2.3. System parameters

The parameter of elastomeric bearing without and with central lead core, namely stiffness (k_b), damping (c_b) and yield strength (F_y) are so selected to provide desired value of isolation period (T_b), damping ratio (ξ_b), and yield strength coefficient (F_0) respectively as

$$T_b = 2\pi\sqrt{\frac{M_t}{\alpha_b k_b}} \quad \xi_b = \frac{c_b}{2M_t\omega_b} \text{ and } F_0 = \frac{F_y}{W_t}$$

where, M_t and W_t are the total mass and weight of building including isolation floor, respectively, k_b and c_b are the stiffness and damping of isolation system respectively, ω_b is the natural frequency of bearing, α_b is the ratio of post to pre-yielding stiffness of bearing.

III. Solution Procedure

Solution of governing motion equation (Eq. 1) with elastomeric base isolated building is obtained by using Newmark's step-by-step method of integration under linear variation of acceleration over a small time interval whereas Eq. 5 is solved by using 4th order Runge-Kutta method. The iterative solution procedure is simulated in MATLAB® coding to determine the structural response of building model.

IV. Numerical Study

A RC building of ten storey in which mass is lumped at each floor equal to 1359.34 ton and that of stiffness 1.08×10^7 kN/m which gives fundamental period of fixed base building equal to 0.47 second . Further, mass of isolation floor is considered as 10% in excess of mass of superstructure floor. The building is subjected to unidirectional excitation for which four real earthquake ground motions are considered, details of which are shown in Table 1 in which earthquake motions designated by EQ1: Imperial Valley1940, EQ2: Kobe 1995, EQ3: Loma Prieta 1989 and EQ4: Northridge 1994. The parameters of base isolation system considered from the reference [8], that is for LRB system as T_b = 2s, and ξ_b = 0.1 whereas for NZ T_b = 1.5s, ξ_b = 0.15 and F_0 = 0.05. The seismic response of building has been simulated with the help of MATLAB platform and hysteretic displacement of bearing is evaluated by Wen's model which is solved by 4th order Runge-Kutta method. The wen's model parameters considered for NZ system by referring [9] are shown in table 2.

The peak response parameters of interest are, time varying top floor displacement (u_f), top floor acceleration (a_f), peak response of top floor displacement, top floor acceleration and bearing displacement. Here, base shear (B_{sy}) and isolation strength (F_y) are normalized by the total weight of building (W_t). The numerical result obtained from the time varying response shown in figure 4 to 7 and is observed that both proposed controls work effectively in reducing the responses of building. Further, the NZ control performs relatively more significant in reducing the responses than LRB control. The peak values of floor displacement and acceleration is shown in table 3 and 4 respectively imply that both proposed controls perform well during various earthquakes. From the table 5, it is observed that peak value of bearing displacement reduces well in reducing the responses under NZ control than LRB control.

V. Conclusion

The study has proposed two seismic controls, that is, LRB control and NZ control to mitigate the responses of ten storied RC building isolated by elastomeric base isolator without and with lead core during excitation due to various earthquakes. From the numerical observations, one can outline the following concluding remarks

(1) The results illustrate that both proposed control strategies perform effectively during earthquakes. Further, the control NZ yield relatively more effective in reducing the responses of building than LRB control.
(2) The peak responses, that is, top floor displacement and acceleration illustrate that the control NZ gives consistent performance in reducing seismic responses as compared to LRB control.
(3) The bearing displacement of isolated building gets reduced well under NZ control than LRB control.

Table 1:- Details of Earthquake ground motions

Earthquake	Recording station	Component	PGA(g)
Imperial Valley,1940(EQ1)	El-Centro	N00E	0.348
Kobe, 1995 (EQ2)	Japan Meteorological Agency	N00E	0.834
Loma Prieta, 1989 (EQ3)	Los Gatos Presentation Centre	N00E	0.570
Northridge, 1994 (EQ4)	Sylmer Converter Station	N00E	0.843

Table 2.Parameters of base isolation system (Wen's model)

Parameter	Value	Parameter	Value
β	0.5	A	1
τ	0.5	n_s	2
q	25 mm	--	--

Table 3: Peak displacement response at each floor (normalized by the respective non-isolated response) under Control-I: LRB Control and Control-II: NZ Control

Floor No.	EQ1		EQ2		EQ3		EQ4	
	Controls		Controls		Controls		Controls	
	I	II	I	II	I	II	I	II
1	0.110	0.158	0.967	0.507	0.215	0.330	0.332	0.494
2	0.208	0.297	1.835	0.960	0.418	0.638	0.641	0.943
3	0.296	0.422	2.610	1.365	0.603	0.929	0.926	1.353
4	0.373	0.53	3.290	1.719	0.769	1.196	1.184	1.722
5	0.438	0.624	3.875	2.042	0.914	1.435	1.411	2.047
6	0.489	0.703	4.364	2.317	1.035	1.641	1.608	2.326
7	0.528	0.769	4.756	2.541	1.132	1.810	1.769	2.555
8	0.561	0.819	5.05	2.713	1.204	1.939	1.893	2.729
9	0.583	0.853	5.246	2.829	1.251	2.027	1.975	2.848
10	0.594	0.87	5.344	2.886	1.274	2.071	2.016	2.908

Table 4: Peak acceleration response at each floor (normalized by the respective non-isolated response) under Control-I: LRB Control and Control-II: NZ Control

Floor No.	EQ1		EQ2		EQ3		EQ4	
	Controls		Controls		Controls		Controls	
	I	II	I	II	I	II	I	II
1	0.176	0.146	0.809	0.460	0.194	0.329	0.371	0.481
2	0.158	0.153	0.813	0.459	0.192	0.297	0.359	0.494
3	0.171	0.159	0.816	0.465	0.197	0.291	0.347	0.478
4	0.145	0.155	0.818	0.466	0.194	0.295	0.331	0.441
5	0.128	0.157	0.821	0.469	0.187	0.286	0.324	0.447
6	0.132	0.157	0.823	0.477	0.198	0.316	0.313	0.456
7	0.124	0.162	0.825	0.482	0.205	0.337	0.332	0.451
8	0.127	0.154	0.826	0.492	0.207	0.359	0.348	0.471
9	0.129	0.163	0.826	0.498	0.216	0.379	0.359	0.491
10	0.157	0.166	0.827	0.507	0.229	0.392	0.381	0.510

Table 5: Peak bearing displacement response under Control-I: LRB Control and Control-II: NZ Control during considered earthquakes

Peak response	EQ1		EQ2		EQ3		EQ4	
	Control		Control		Control		Control	
	I	II	I	II	I	II	I	II
Bearing displacement (cm)	6.95	6.10	28.15	19.93	13.89	11.60	23.54	19.99

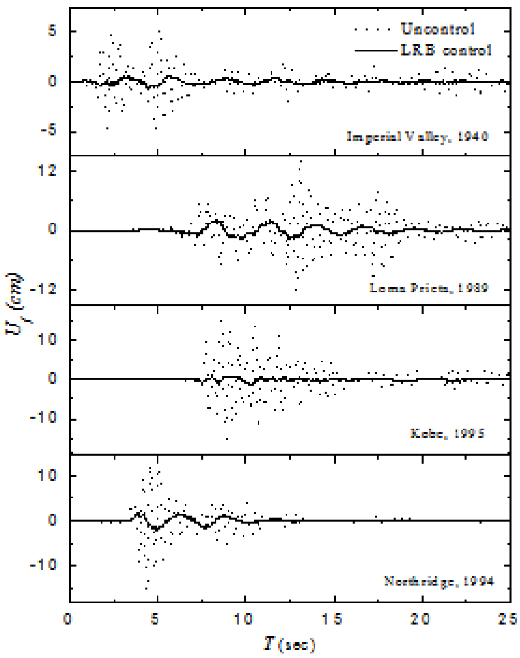

Fig. 4. Time varying top floor displacement response under LRB control

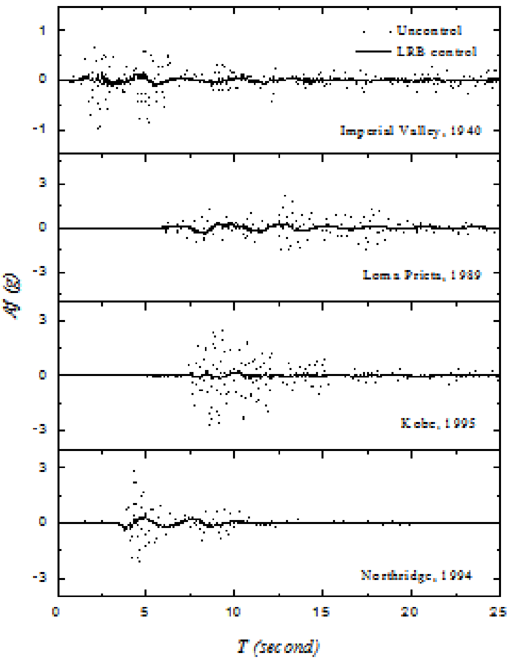

Fig. 5. Time varying top floor acceleration response under LRB control

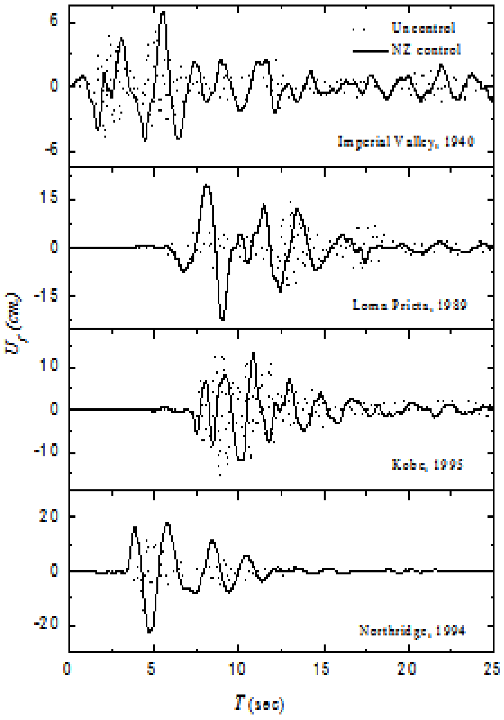

Fig. 6. Time varying top floor displacement response under NZ control

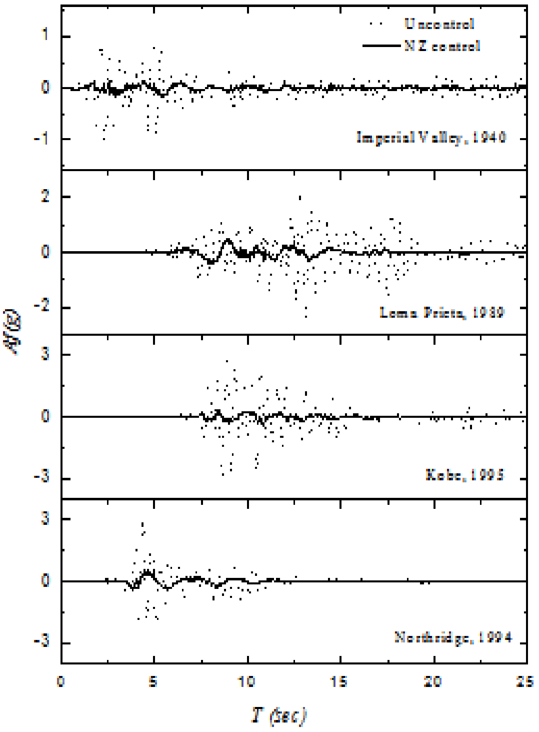

Fig. 7. Time varying top floor acceleration response under NZ control

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