International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-05, Issue-02, May 2019

Earthquake Response of Base Isolated Building Under Near -Fault Earthquakes

*Anju Agarwal, #Nirendra Dev

*Research Scholar, #Professor, Delhi Technological University, New Delhi, India,

*anjagarwal31@gmail.com, #nirendra61@gmail.com

Abstract: Conventional isolation systems may effectively reduce the responses of structures during regular earthquakes, but they are vulnerable to a low-frequency resonance problem when subjected to a near-fault ground motions. Ground motions in the near fault zone depend upon rupture mechanism and the slip direction relative to the site. The permanent ground displacements at the site due to tectonic movements also influence the ground motion. The two main features associated with near fault ground motion is the forward directivity and the fling effect. The near fault ground motions can cause considerable and severe damage to structures designed to comply with the criteria for far-field earthquakes. This paper thus investigates the seismic response of base isolated structures with lead rubber bearing (LRB) when subjected to near- field ground motion. A seismic evaluation of the building for near-field ground motion is carried out using analytical model. Seven different models from three story to nine story are considered for three different near fault ground motions. After analysis it is found that the velocity pulses associated with near fault ground motions can significantly influence the responses of the base isolated structures and if preventive measures are not considered, severe unforeseen damages to the structure may result.

Keywords — Base Isolation, Near fault ground motions, Lead Rubber bearings, Seismic response.

I. INTRODUCTION

The base-isolation technique is found to be effective for the seismic protection of reinforced concrete moment resisting framed buildings which are to be constructed and also for the seismic retrofitting of existing structures. In this design approach the structure is protected from the seismic forces by the use of bearings which reduce the transmission of the horizontal acceleration into the superstructure. This method involves the reduction of the fundamental frequency and to provide an additional means by which energy can be dissipated out of the superstructure such that the accelerations transmitted to the super structure are considerably reduced [1,2]. Guidelines for the design of base isolated structures are now, readily available and well developed in some countries like the U.S.A, Japan and New Zealand.

However, under near-fault ground motions, the base isolated structures can show a different behaviour. Ground motions caused due to earthquakes in the vicinity of causative faults are unique and can be remarkably different from those observed at far-fault [3,4]. These waves possess large-velocity pulses and show large-displacements resulting in oversizing of the isolation system and may also result in the amplification of the structural response. These waves possess the capability to cause severe damage to the base isolated structure earlier thought to be seismically well protected. Thus, the building codes earlier developed were found to be not sufficient for design of base isolated structures under near-fault ground motions. After the 1994 Northridge, California earthquake, the influence of the near fault pulses on the structural performance of the long period structures was duly felt and the influence of near-fault motions on a structure became the objective of research for engineers as well as seismologists[5].

The forward directivity effect and the fling effect were the two main objective of research worldwide [6]. The forward-directivity is dependent on the type of rupture and the direction of slip relative to the strike. It is categorized by a large pulse occurring at the beginning of the ground motion and it is oriented in the perpendicular direction to the fault

DOI : 10.35291/2454-9150.2019.0074

plane. The fling step depends upon the deformations due to tectonic causes. These are parallel to the strike of the fault for strike-slip earthquakes and normal to the strike of the fault for dip-slip earthquakes [7].

According to Jangid [8], Chimamphant et al. [9] and Makris [10] the base-isolated buildings might perform poorly because of large isolator displacements due to long period pulses associated in the NFE. This led to considerable interest by the researchers; studies of the dynamic behavior of base-isolated buildings under NFE have been reported by Markis [11], Liao et al. [12] and Jangid [10]. The bearing displacements under NFEs are found to be significantly large which can cause instability in the isolation system. Also, according to Jangid and Kelly [13], the fault-normal ground motion is richer in long-period spectral components than that of the fault-parallel with the peak displacement in the fault-normal and fault-parallel direction occurring at a different time and the presence of long-duration pulses that has the tendency to strongly impact base isolation systems. One or more number of such displacement pulses may exist in the ground motions which will have a large influence on base-isolated structure with a period ranging from 1 to 3 sec and can cause a large isolator displacement.

The seismic response of base-isolated structures with LRB subjected to NFE was also investigated by Sarbatdar et al. [14]. It is found that the large displacement and velocity pulses in near-fault ground motions can significantly affect the seismic response of base-isolated structures. Kelly [15] suggested that one of the solutions for this is to accommodate the large displacements be by using large isolators. However, this method may not be economical owing to the fact that larger displacements at the isolator level raise stability issues which increase the requirements of the isolation systems.

This paper investigates the influence and effectiveness of using LRB on the response of lead rubber bearing base isolated building under near field earthquake. The main objectives of the study are: (i) to study the performance of structures isolated by LRB under near field earthquakes, and (ii) to investigate the optimum height for a medium rise building for which the LRB are most effective, with respect to controlling the isolator displacement under near-field earthquakes.

II. MODELING OF BASE-ISOLATED BUILDING WITH LEAD RUBBER BEARING

For the purpose of the present study seven different models from three story to nine story are considered for three different near fault ground motions. Reinforced concrete frame building have been considered and modeled in SAP 2000 v 16.6.2 software. The structural system under consideration is an idealized shear type building mounted on the LRB system. Central lead-core provides a means of additional energy dissipation and reduced bearing displacement. It also provides initial rigidity against wind loads and minor earthquakes. The force-deformation behavior of the lead-rubber bearing is non-linear hysteretic. The assumptions made in modeling the building are (i) only one lateral degree of freedom at each floor level is considered, (ii) the floors of the superstructure are considered to be infinitely stiff in their own plane, (iii) the effects of soil-structure interaction are neglected, (iv) only a single horizontal component of the earthquake ground motion is applied to the structure at a time, (v) the effects of the vertical component of the earthquake excitation are neglected, (vi) the force-deformation behavior of the superstructure is considered to be linear and that of the LRB is bilinear. Also, Newmark’s step-by-step incremental method is used assuming linear variation of acceleration over a small time interval (Δt) as the classical modal superposition technique is not applicable due to non-linear force deformation behavior of the isolator and also the difference between the damping of the isolation system and the superstructure. Schematic representation and force-deformation behavior of lead rubber bearings used in the present study are shown in Figure 1.

The force-deformation behavior of the LRB is defined by the parametric quantities which are the normalized yield strength (Fo = Fy/W), where W = mg is the total weight of the base-isolated building and g is the acceleration due to gravity, post yield stiffness (kb) and isolator yield displacement q as depicted in Fig. 1(c). The damping coefficient (cb) and isolation stiffness (kb) are selected to

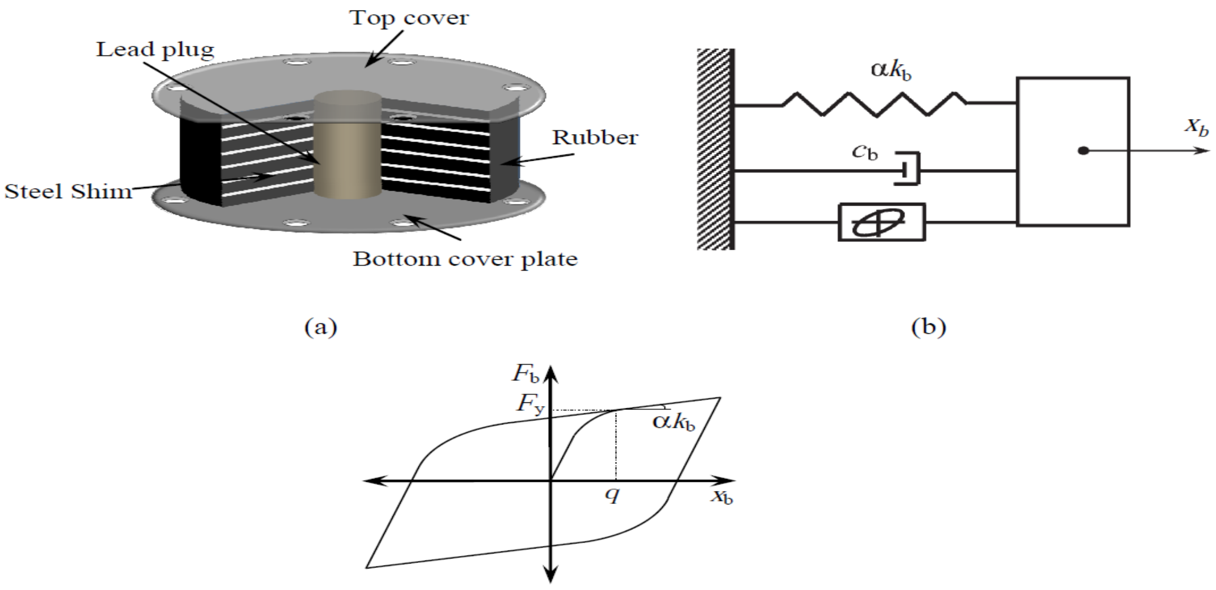
DOI : 10.35291/2454-9150.2019.0074

provide specific values of damping ratio (ξb) and isolation period (Tb), respectively, using the following expressions

$$c_{\mathrm{b}} = 2\xi_{\mathrm{b}} m\omega_{\mathrm{b}} \qquad (1)$$

$$k_{\mathrm{b}} = m\left(\frac{2\pi}{T_{\mathrm{b}}}\right)^{2} \qquad (2)$$

Where, m is the total mass of the base-isolated building and the base isolation frequency $\omega_{\mathrm{b}} = 2\pi / T_{\mathrm{b}}$.



(a) (b)

(c)

Figure 1. (a) LRB isolator (b) schematic diagram of LRB (c) force-deformation of LRB

III. NUMERICAL STUDY

The seismic response fixed base frame and lead rubber bearing frame models are investigated under real earthquake ground motion records. Three near fault earthquakes with varying Richter scale magnitudes are used for the study. The peak ground accelerations (PGAs) and other relevant details of the selected ground motion data are shown in Table 1. LRB system is modeled using isolation period (Tb), damping ratio (ξb), normalized yield strength (Fo), and isolator yield displacement (q). A uniform damping ratio (ξs) of 0.02 is taken for the superstructure. All floor masses are taken to be equal and the floor stiffness is decided in such a way that a required fundamental time period of the fixed-base building (T) is obtained. The values considered in the present study for ξb are 0.15; for Tb are 2.5, for Fo are 0.075 and for q are 5 cms respectively.

Table 1. List of near-fault and far-fault earthquake ground motions used in the study.

No.	Earthquake Name	Year	Station Name	Mw	PGA(g)	NF/FF
1	Loma Prieta	1989	Los Gatos Presentation Centre (LGPC)	6.93	0.97	NF
2	Kobe	1995	Kobe Japan Meteorological Agency (KJMA)	6.90	0.83	NF
3	Northridge	1994	Sylmar- Hospital	6.7	0.84	NF

For every earthquake ground motion seven different analysis have been performed by varying the story height. Hence, a total of twenty one different analysis have been used in the present study. The variations of peak top floor acceleration and isolator displacement for both fixed base model and lead rubber bearing frame models have been obtained.

Table 2, table 3 and table 4 give the values of peak isolator displacement and peak top floor acceleration for the three different ground motions considered for the present study. Peak top floor acceleration values are calculated for both the fixed base frame base isolated frame. The time period for the super structure are considered to be 0.3 sec, 0.4 sec, 0.5 sec, 0.6 sec, 0.7 sec, 0.8 sec and 0.9 sec for the three, four, five, six, seven, eight and nine storey building frames respectively.

Table 2. Peak isolator displacement and peak top floor acceleration for Loma Preita

No. of storey	Peak isolator displacement (cms)	Peak top floor acceleration (g)		
		Fixed Base Frame	Base Isolated Frame	Percentage Reduction
3	47.87	2.41	0.42	82.57
4	47.75	2.08	0.44	78.85
5	47.40	2.88	0.44	84.72
6	47.23	3.09	0.52	83.17
7	46.96	3.72	0.48	87.09
8	47.09	3.00	0.50	83.33
9	46.90	2.52	0.56	77.77

Table 3. Peak isolator displacement and peak top floor acceleration for Kobe

No. of storey	Peak isolator displacement (cms)	Peak top floor acceleration (g)		
		Fixed Base Frame	Base Isolated Frame	Percentage Reduction
3	21.04	2.11	0.27	87.20
4	20.67	3.58	0.31	91.34
5	20.49	3.61	0.34	90.58
6	19.36	2.60	0.57	78.07
7	19.45	4.01	0.53	86.78
8	19.10	2.76	0.54	80.43
9	18.28	3.00	0.69	77.70

Table 4. Peak isolator displacement and peak top floor acceleration for Northridge

No. of storey	Peak isolator displacement (cms)	Peak top floor acceleration (g)		
		Fixed Base Frame	Base Isolated Frame	Percentage Reduction
3	37.47	3.65	0.51	86.02
4	37.35	4.18	0.40	90.43
5	37.08	3.61	0.39	89.19
6	37.42	1.97	0.53	73.09
7	36.05	1.98	0.57	71.21
8	35.76	1.43	0.61	57.34
9	36.30	1.53	0.54	64.70

DOI : 10.35291/2454-9150.2019.0074

The least isolator displacements are observed for Kobe ground motion and the maximum isolator displacements are observed for Loma Prieta ground motion. This implies that the peak isolator displacement is related to the peak ground acceleration of a ground motion. The change in peak isolator displacement for Loma Prieta, Kobe and Northridge ground motions as we move from a three storey base isolated structure to nine storey base isolated structure is 0.97cms, 2.76cms and 1.17cms respectively. For Loma Prieta ground motion the isolator displacements are found to be maximum as shown in Table 2. but the change in displacement observed from three to nine storey is the least. For Kobe ground motion the isolator displacements are found to be minimum as shown in Table 3. but the change in displacement observed from three to nine storey is the maximum. In general, as the number of storeys goes on increasing the peak isolator displacement goes on decreasing.

The maximum percentage reduction in peak top floor accelerations for Loma Prieta, Kobe and Northridge are 87.09, 91.34 and 90.43 respectively. This implies that the peak top floor acceleration is related to the peak ground acceleration of a ground motion. In general, as the number of storeys goes on increasing the percentage reduction in peak top floor acceleration goes on decreasing.

IV. CONCLUSION

From the trends of the results of the present analytical study the following conclusions may be drawn:

(1) Lead rubber bearing frame building is designed to increase the time period of the structure, which helps in reduction of the response in the building subjected to strong ground motion earthquakes.

(2) Lead rubber bearing systems introduce high non-linearity in the system, hence a non-linear time history analysis has been performed. It is observed that as the storey height increases from three to nine storeys the bearing displacement goes on decreasing for all the three ground motions considered.

(3) The peak top floor acceleration of the base isolated buildings are considerably less to that of fixed base buildings and hence depend upon the flexibility of the structure.

(4) The peak top floor accelerations and the peak isolator displacement depends upon the earthquake ground motion.

(5) As the number of storeys goes on increasing the percentage reduction in peak top floor acceleration and the peak isolator displacement goes on decreasing.

(6) Based on the present study the optimum storey height for which base isolation is found to be effective is between six to eight storeys.

Thus, base isolation using lead rubber bearings is beneficial in reducing the peak top floor acceleration but the isolator displacements under near fault motions are huge and a study can be initiated to reduce them. Also, a study can be initiated to understand the how the isolator damping and base shear are affected with the increase in storey height.

REFERENCES

[1] J.M. Kelly, A seismic base isolation: review and bibliography. Soil Dynamics and Earthquake Engineering 5, 202-216 (1986).

[2] I.G. Buckle, R.L.Mayes, Seimic isolation: history, applications and performance-A world over-view. Earthquake Spectra 6 (2), 161-202 (1990).

[3] J.F. Hall, T.H. Heaton, M.W. Halling, D.J. Wald, Near-source ground motions and its effects on flexible buildings. Earthquake Spectra 11(4), 569-605 (1995).

[4] T.H. Heaton, J.F. Hall, D.J. Wald, M.W. Halling, Response of high-rise and base-isolated buildings to a hypothetical MW 7.0 blind thrust earthquake. Science 267, 206-211 (1995).

[5] P.K. Malhotra, Response of buildings to near-field pulse like ground motions. Earthquake Engineering and Structural Dynamics 28, 1309-1326 (1999).

[6] G.P. Mavroeidis and A.S. Papageorgiou, A mathematical representation of near-fault ground motions Bulletin of the seismological society of America 93(3) : 1099-1131 (2003).

[7] P.G. Somerville, N.F. Smith, R.W. Graves and N.A. Abrahamson, Modification of Empirical strong ground motion Attenuation relations to include the amplitude and duration effects of rupture directivity, Seis Res let, 68(1) : 199-222 (1997).

[8] R.S Jangid, Optimum lead-rubber isolation bearings for near-fault motions, Engineering Structures, 29, 2007, 2503-2513.

[9] S Chimamphant, K Kasai, Comparative Response and Performance of Base Isolated and Fixed Base Structures, Earthquake Engineering & Structural Dynamics, 45, 2016, 5–27.

[10] N Makris, Seismic isolation: Early history, Earthquake Engineering and Structural Dynamics, 48(2), 2019, 269-283.

[11] N Makris, Rigidity–plasticity–viscosity: Can electro-rheological dampers protect base-isolated structures from near-source ground motions? Earthquake Engineering and Structural Dynamics, 26, 1997, 571–591.

[12] W.I Liao, C.H Loh, B.H Lee, Comparison of dynamic response of isolated and non-isolated continuous girder bridges subjected to near-fault ground motions, Engineering Structures, 26, 2004, 2173–2183.

[13] R.S Jangid, Optimum friction pendulum system for near-fault motions, Engineering Structures, 27, 2005, 349–359.

[14] M.K Sharbatdar, V.S.R Hoseini, G.G Amiri, H Naderpour, Seismic response of base-isolated structures with LRB and FPS under near-fault ground motions, Procedia Engineering, 14, 2011, 3245-3251.

[15] J. M Kelly, The role of damping in seismic isolation, Earthquake Engineering and Structural Dynamics, 28(1), 1999, 3-20.

DOI : 10.35291/2454-9150.2019.0074