International Journal of the Physical Sciences Vol. 6(9), pp. 2219-2228, 4 May, 2011
Available online at http://www.academicjournals.org/IJPS
DOI: 10.5897/IJPS10.441
ISSN 1992 - 1950 ©2011 Academic Journals

Full Length Research Paper

Study on optimal isolation system and dynamic structural responses in multi-storey buildings

A. B. M. Saiful Islam*, Mohammed Jameel and Mohd Zamin Jummat

Department of Civil Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia.

Accepted 04 April, 2011

Seismic base isolation systems have been investigated in this study to be acquainted with the optimized insertion in multi-storey buildings. Two extensively exploited isolator types, namely, lead rubber bearing (LRB) and high damping rubber bearing (HDRB) are incorporated to examine their effect for buildings. Both time history and response spectrum based non linear finite element analyses are conducted using SAP 2000 program as analysis tool. Isolators are designed as per UBC code. Bi-directional site specific earthquake records have been used as seismic load. Analyses results show that isolation system considerably reduce earthquake induced load on building. Furthermore, method of analysis has been found to have considerable effect on the response of low to medium rise buildings. Time history analysis shows significant less base shear than that from response spectrum analysis. Also, less isolator displacement is obtained from time history analysis than that from response spectrum analysis. Considering isolator displacement and base shear, HDRB is found to be better of the two types of isolators adopted in this study. Nevertheless, LRB is stumbled on to be more effectual in reducing individual floor acceleration and thereby reducing non structural damages.

Key words: Optimal isolation system, response spectrum analysis, time history analysis, lead rubber bearing (LRB), high damping rubber bearing (HDRB), bi-directional earthquake, low to medium rise buildings, flexibility, seismic resistance.

INTRODUCTION

Seismic isolation is the separation of the structure from the harmful motions of the ground by providing flexibility and energy dissipation capability through the insertion of the isolated so called isolators between the foundation and the building structure (Ismail et al., 2010).

Unlike the conventional design approach, which is based upon an increased resistance (strengthening) of the structures, the seismic isolation concept is aimed at a significant reduction of dynamic loads induced by the earthquake at the base of the structures themselves (Micheli et al., 2004).

Invention of lead rubber bearing (LRB, 1970's) and high damping rubber (HDR, 1980's) gives a new dimension to the design of base isolated structure (Buckle and Mayes, 1990; Hussain et al., 2010; Islam, 2009).

The use of elastomeric bearings, such as high damping rubber bearings (HDRB) and lead rubber (LRB) bearings have been moved to a popular phenomena in recent days. A number of both past and recent researches in the area of base isolation have spotlighted on the innovation (Providakis, 2008; Islam et al., 2010a). Jangid (2007) and Providakis (2008) investigated seismic responses of multi- storey buildings for near fault motion isolated by LRB. Islam et al. (2010c) has studied isolation system at low to medium risk seismicity. Dall'Asta and Ragni (2006, 2008) have covered experimental tests, analytical model and nonlinear dynamic behavior of HDRB. Bhuyan (2006) has developed a rheology model for high damping rubber bearing for seismic analysis identifying nonlinear viscosity. Although it is a relatively recent technology, seismic isolation for multi storey buildings has been well evaluated and reviewed (Hong and Kim, 2004; Barata and Corbi, 2004; Agarwal, 2007; Komodromos, 2008; Lu and Lin, 2008; Spyrakos, 2009; Panayiotis et al., 2010, Islam et al., 2011a and b). Base isolator with hardening behaviour under increasing load has been developed for medium-rise buildings (up to four storeys) and sites with

*Corresponding author. E-mail: abm.saiful@gmail.com. Tel: +60102573287. Fax: +60379675318.

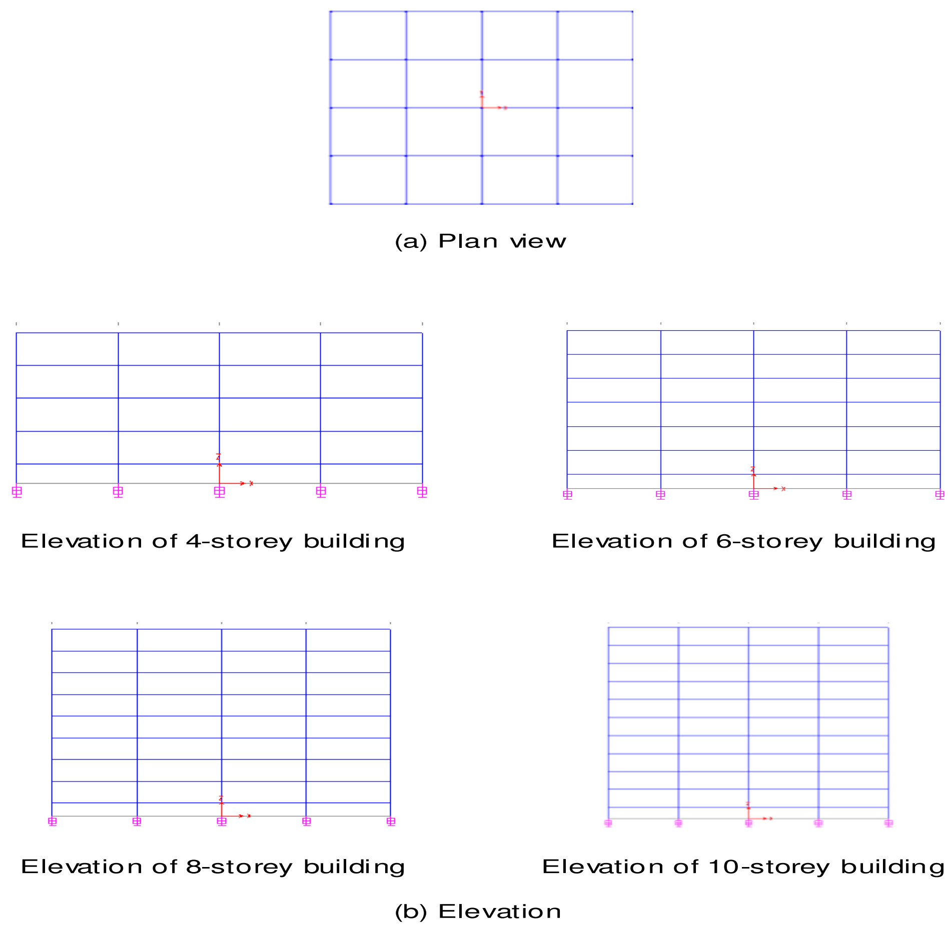

Figure 1. Plan and elevation of the buildings.

moderate earthquake risk (Pocanschi and Phocas, 2007). Nonlinear seismic response evaluation was performed by Balkaya and Kalkan (2003). Resonant behaviour of base-isolated high rise buildings under long-period ground motions was dealt by Ariga et al. (2006) and long period building responses by Olsen et al. (2008). Wilkinson and Hiley (2006) presented a non-linear response history model for the seismic analysis of high-rise framed buildings. Ebisawa et al. (2000), Dicleli and Buddaram (2007), Casciati and Hamdaoui (2008) and Di Egidio and Contento (2010) have also given effort in progresses of isolated system.

Though the application of isolator is going to be very familiar all over the world, there is a lack of proper research to implement the device practically for local buildings in Dhaka, Bangladesh region as per the local requirements. So through study in this concern is a very burning matter. Many types of isolation system have been developed elsewhere in the world to provide flexibility and damping to a structure in the event of seismic attack. Among the categories, lead rubber bearing (LRB) and high damping rubber bearing (HDRB) are the most commonly used isolator nowadays. However, there are few work that has been done as yet to examine the effect of incorporating these isolators to a building located in Dhaka considering its' soil and seismic conditions. Consequently, little is known about the exact extent of change in structural behaviour of a building located in Dhaka if LRB or HDRB is incorporated. With these as background, present paper examines the behaviour of building located in Dhaka isolated by both LRB and HDRB. Using SAP 2000 as analysis and design tool, the effect of changing isolator properties on the building behaviour is extensively examined. Response spectrum and time history analyses under bidirectional earthquake history have been carry out. From these, guidelines for selecting appropriate isolator for a building in Dhaka are also proposed.

MATERIALS AND METHODS

Building configuration

Four moment resisting frame buildings located at Dhaka, Bangladesh of squared plan size at 4 span @ 7.62 m at both directions having 4, 6, 8 and 10 storey shown in Figure 1 were used in the analytical study. For each building total seismic weight were

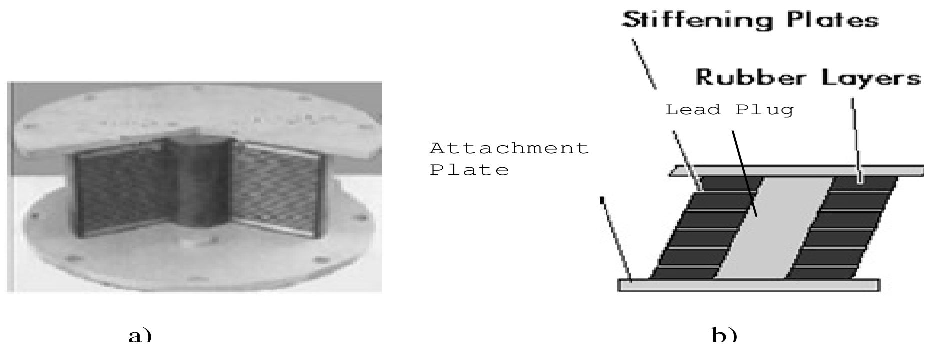

Figure 2. Lead rubber bearing, (a) Geometry and (b) Deformation due to loading.

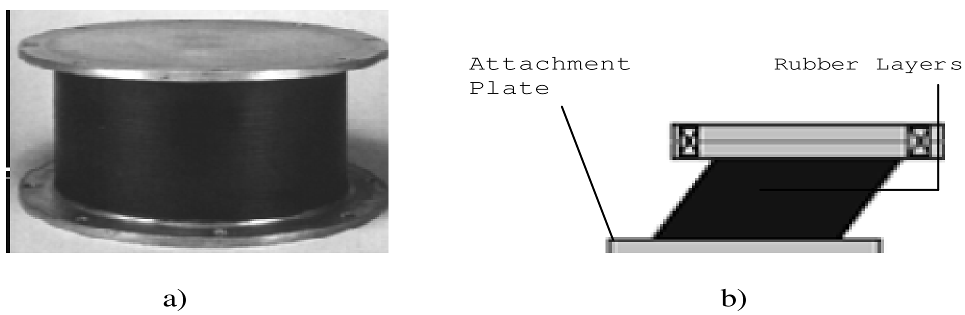

Figure 3. High damping rubber bearing, (a) Geometry and (b) Deformation due to loading.

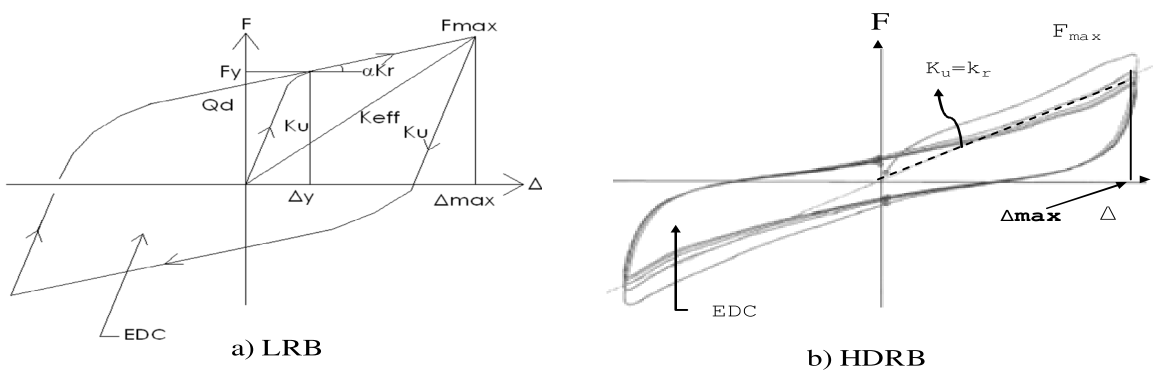

Figure 4. Idealized non-linear force-displacement curve of bearing. F_{max} = Maximum force, Kr = Post-elastic stiffness, K_u = Elastic (or unloading) stiffness, Qd = Characteristic strength, F_y= Yield force, K_{eff}= Effective stiffness, Δ_{max}= Maximum bearing displacement, Δ_y= Yield displacement, EDC= Energy dissipated per cycle = Area of hysteresis loop.

assumed to be distributed equally over all floors including the base floor as well as equally over all columns. This assumption allowed the same isolation systems to be used for all columns in a building.

Design of isolator

A total of 16 variations of both LRB and HDRB were used for the evaluation. The designs were completed using the excel spreadsheet BEADES 2010 which implements the design procedures as per UBC (1997). The bearings are linked at the bottom of each column. LRB is formed of a lead plug force-fitted into a preformed hole in a low damping elastomeric bearing (Win, 2008) as shown in Figure 2. Whereas, HDRB consists of thin layers of high damping rubber and steel plates built in alternate layers as shown in Figure 3. From displacement behaviour of LRB and HDRB are shown in Figure 4. The design basis include S_3 type soil profile for Dhaka having seismic zone coefficient, Z = 0.15 and beyond 15

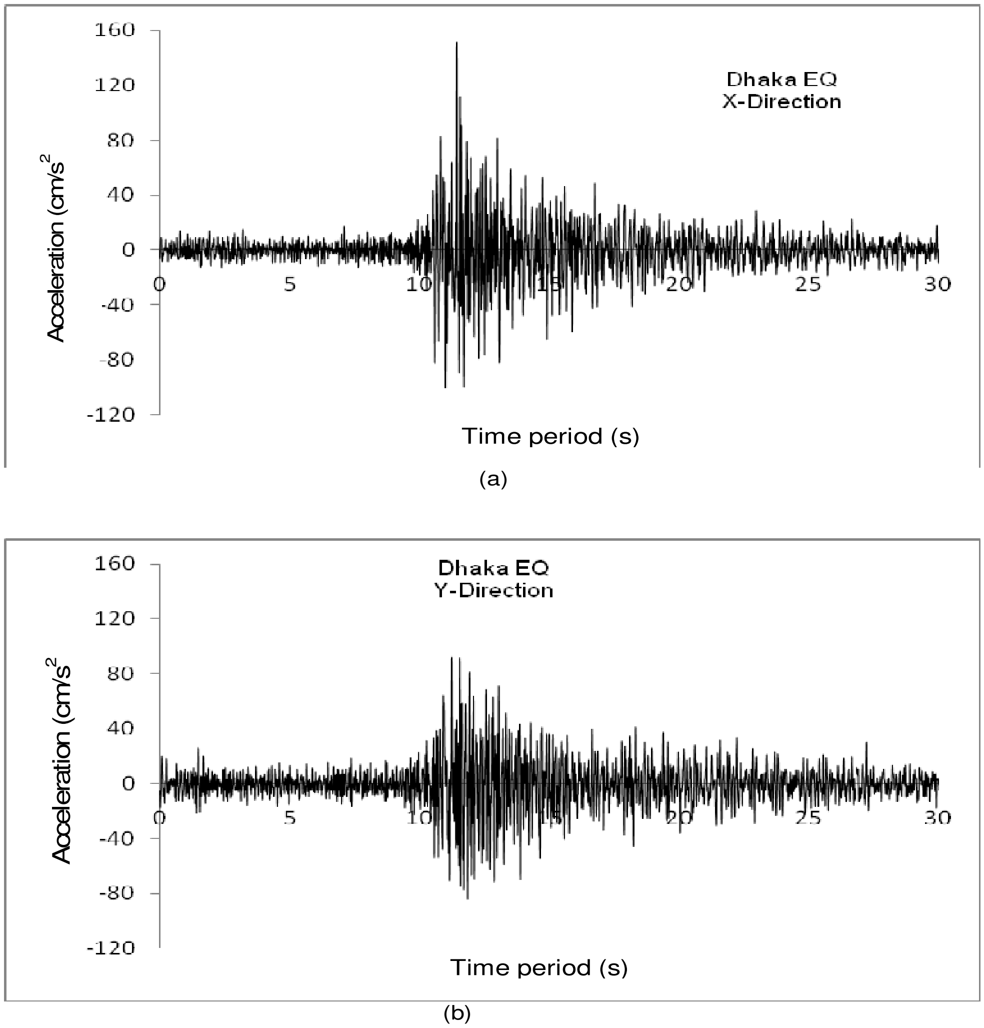

Figure 5. Time history for Dhaka EQ (a) X-direction and (b) Y-direction.

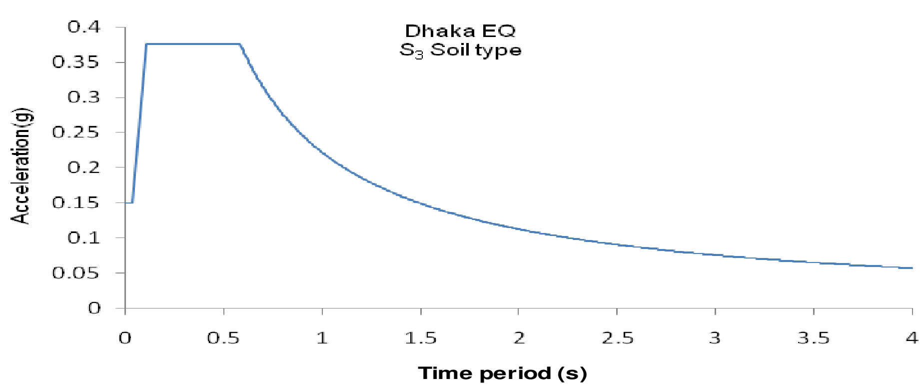

Figure 6. Response spectrum for Dhaka EQ.

km of a Type A fault. The recently occurred Natore Earthquake scaled as to produce the desired earthquake load for Dhaka buildings (Islam et al., 2010b) have been used. Time history and corresponding response spectrum for 5% damping is illustrated in Figures 5 and 6 respectively for this record. This is the design basis earthquake (DBE) which is used to evaluate the structural

Table 1. Isolation system properties.

System label	Characteristic strength (Q_d)	Period of isolator (s)	Damping β (%)	Initial stiffness K_1 (KN/mm)	Post-yi eld stiffness K_2 (KN/mm)	Yield force Fy KN
LRB1	0.050	1.5	8	14.46112	1.40297	330.1
LRB1		2	11	12.20158	1.11331	328
LRB1		2.5	15	10.16795	0.85849	325.6
LRB1		3	20	9.038179	0.71944	323.9
LRB2	0.075	1.5	13	14.46112	1.40297	495.2
LRB2		2	20	12.20158	1.11331	492
LRB2		2.5	26	10.16795	0.85849	488.4
LRB2		3	31	9.038179	0.71944	485.8
LRB3	0.100	1.5	20	14.46112	1.40297	660.2
LRB3		2	28	12.20158	1.11331	656.1
LRB3		2.5	33	10.16795	0.85849	651.1
LRB3		3	37	9.038179	0.71944	647.8
HDR		1.5	15	11.08494	3.0338	225.2
HDR		2	16	10.97653	2.45166	223
HDR		2.5	17	10.9324	2.00105	222.1
HDR		3	19	10.92102	1.55656	221.9

response. The maximum capable earthquake (MCE) which is a function of DBE is used to obtain maximum isolator displacements.

Each isolation system was defined with effective periods of 1.5, 2.0, 2.5 and 3.0 s, which covers the usual range of isolation system period. Table 1 lists the variations considered in the evaluation and the hysteresis parameters used for modeling.

OBSERVATION AND RESULTS

Evaluation procedure

The procedures for evaluating isolated structures are in increasing order of complexity, (1) static analysis, (2) response spectrum analysis and (3) time-history analysis. Only response spectrum and time history analysis is considered here. Designing isolator is based on an effective stiffness formulation and so is usually an iterative process. The effective stiffness is estimated, based on estimated displacements, and then adjusted depending on the results of the analysis. At each analysis the accelerations and displacements at each level were saved as were the shear forces in each storey. These values were then processed to provide isolator displacements and base shears.

Building inertia load

The isolation system response provides the maximum lateral load at base that is the maximum simultaneous summation of the inertia forces from all levels above the isolator plane. The inertia forces at different floors are obtained from the response spectrum analyses, where modal inertia forces are the product of the floor acceleration times the participation factor times the mass. Figure 7 plots these distributions from response spectrum analyses for four building configurations, each for one isolator effective period.

From the results shown, it may be seen that incorporation of isolation reduces building inertia forces drastically. The effect is more pronounced in upper floors where the reduction may be in the order of 65%. To compare these results, the force distributions in Figure 8 have been generated using time history method in turn. These results emphasize the limited application of a static force procedure for the analysis and design of base isolated buildings as the distributions vary widely. Reduction in inertia forces derived from time history analysis is found to be 15 to 30% lower than response spectrum analysis. Again, reduction of inertia forces is found to be greater in case of LRB than HDRB for all the cases in response spectrum analysis. However, in time history analysis, this is true only for the cases when period of LRB is greater than 2.5 s.

Base shear

The response spectrum as well as time history results are plotted in Figure 9 for the base shear coefficients which is

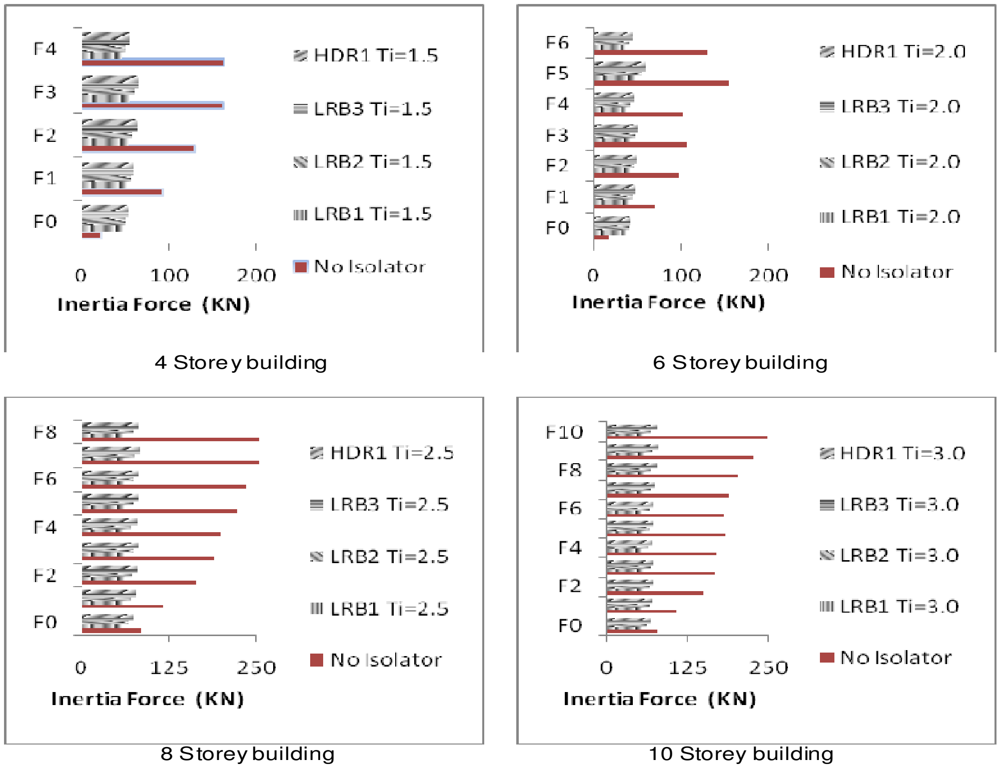

Figure 7. Floor-wise inertia forces in response spectrum analysis.

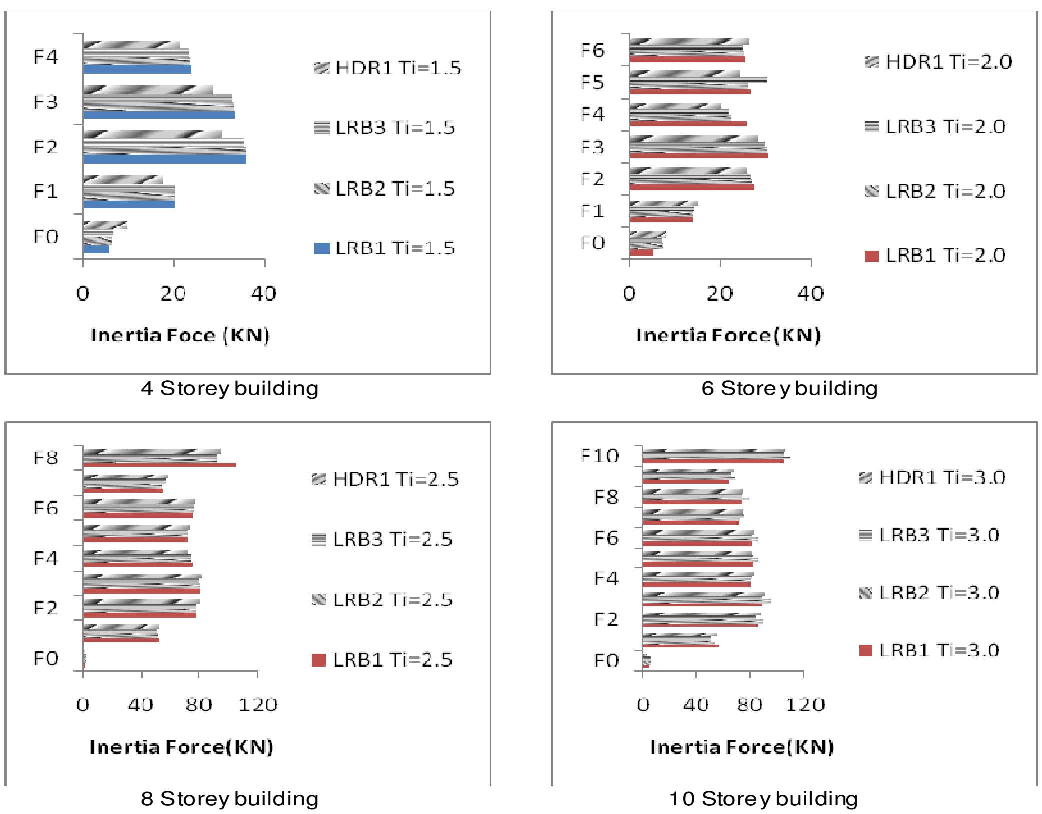

Figure 8. Floor-wise inertia forces in time history analysis.

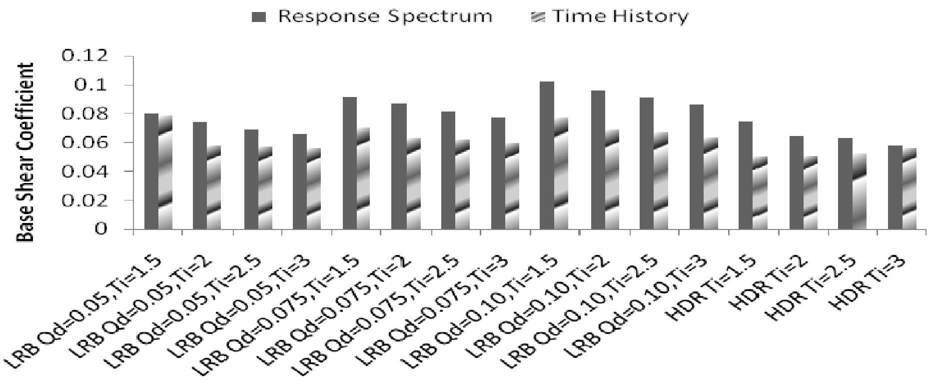

Figure 9. Base shear coefficient for 10 storey building.

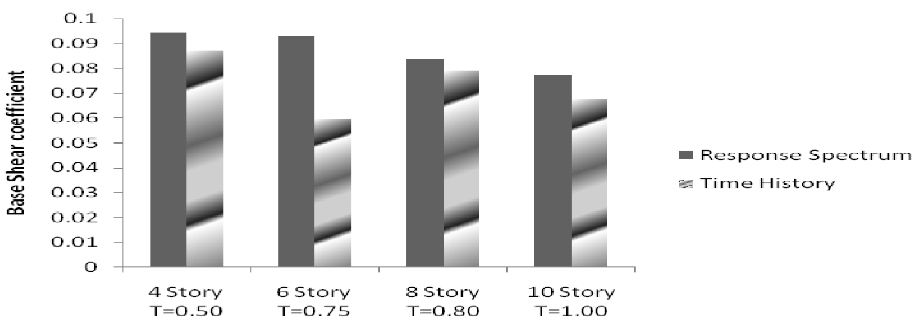

Figure 10. Base Shear coefficient for four buildings with LRB1, Ti=1.5 s.

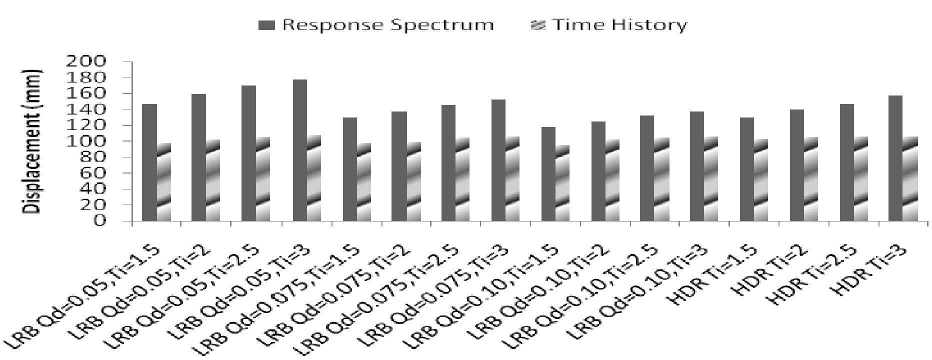

Figure 11. Isolator displacement for 10 storey building.

defined as the ratio of base shear to weight of the building. Figure 10 shows base shear coefficient for four types of building considered for a common type of isolator (LRB1, T_i = 1.5 s). From these figures, it may be seen that base shear coefficient decreases with increasing isolator period. Again, about 12 to 24% lower value of base shear coefficient is found from time history analysis than from response spectrum analysis. Furthermore, it is evident from Figure 9 that HDRB is more efficient is reducing base shear coefficient than LRB. From Figure 10 it may also be seen that as the building period increases the effects of building flexibility become more important and consequently the coefficient decreases for the buildings with longer periods.

Isolator displacement

Figure 11 shows isolator displacement for 10 storey building for different types of isolator. From this Figure 11,

`

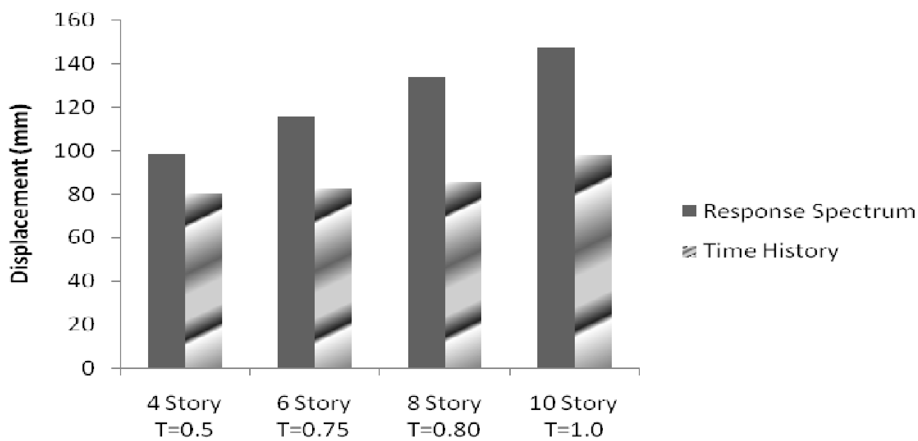

Figure 12. Isolator displacement for four buildings with LRB1, Ti=1.5 s.

Table 2. Governing base shear coefficients and isolator displacements.

System	Characteristic Strength (Q_d)	Period of Isolator (s)	B (%) Damping	Displacement Δ (mm)	Base shear coefficient C
LRB1	Qd=0.050	1.5	8	183.134	0.0952
LRB1		2	11	222.504	0.0825
LRB1		2.5	15	253.238	0.0819
LRB1		3	20	273.558	0.0814
LRB2	Qd=0.075	1.5	13	156.464	0.1246
LRB2		2	20	182.372	0.1238
LRB2		2.5	26	211.074	0.1228
LRB2		3	31	238.506	0.1222
LRB3	Qd=0.100	1.5	20	136.906	0.1661
LRB3		2	28	164.846	0.1651
LRB3		2.5	33	194.31	0.1638
LRB3		3	37	223.012	0.1629
HDR		1.5	15	152.146	0.0791
HDR		2	16	198.374	0.0655
HDR		2.5	17	242.57	0.0652
HDR		3	19	279.146	0.0651

isolator displacement from time history analysis is found to 15 to 50% less than that from response spectrum analysis. Again, Figure 12 shows isolator displacement for four types of building considered for a common type of isolator (LRB1, T_i = 1.5 s). From these figures, it is evident that isolator displacement increases with increasing isolator period as well as building period. Time history analysis also shows this trend but degree of sensitivity is far less than that from response spectrum analysis. Furthermore, HDR, in comparison to LRB is more effective in checking isolator displacement. For LRB, isolator displacement decreases with increasing characteristic strength, Q_d.

Summary of results

The isolator displacement and base shear coefficient values for the 16 considered isolation systems have been listed in Table 2 to evaluate its selection as per design criteria. Response spectrum analysis gives higher values for all of the building responses that were analyzed and therefore gives the critical results. The HDRB systems with Ti = 3.0 s provides the smallest base shear coefficients. This is followed by other types of HDRB with their decreasing period. Increasing base shear coefficient is found from LRB with its increasing characteristic strength, Qd. As the base shear coefficients decreases a simultaneous increase in isolator displacement is observed. The HDRB systems with relatively short isolated periods are found to be the most efficient in controlling isolation system displacements. From the floor accelerations data for different building periods from the four buildings, it may be seen that LRB with Qd = 0.05 yields the minimum values. From these results, it may be stated that there is no unique isolation system that is optimum for building in Dhaka. For choosing isolator type for a building in Dhaka, the three criterions i.e. base shear coefficient, isolator displacement and floor acceleration should be simultaneously considered and an optimum solution should be obtained.

Conclusions

This paper investigated the effects of seismic base isolation through LRB and HDRB on multi-storey buildings. It addressed an important practical issue which points into drastic reduction of structural responses due to seismic excitation. Isolation system considerably reduce earthquake induced load on building. Furthermore, methods of analysis have been found to have considerable effect on the response of building. Time history analysis shows 12 to 24% less base shear than that from response spectrum analysis. Also, less isolator displacement is obtained from time history analysis than that from response spectrum analysis. Considering isolator displacement and base shear, HDRB is found to be better of the two types of isolators considered in this study. However, LRB is found to be more effective in reducing individual floor acceleration and thereby reducing non structural damages.

In this case, the most effective choice is considered of HDRB and LRB bearings, as resulting in a lower isolation frequency and then in lower peak structural parameters, but the isolation choice should generally be based on the best compromise between the reduction of floor accelerations and the amplification of building rigid body displacements. Other isolation systems can also be incorporated to justify the optimization.

It should be pointed out that this investigation was based on soft to medium soil at free field excitations in accordance with the site specific bilateral EQ data. However, for applications on buildings on soft soils where more significant long period excitations are to be taken into account, the design of the base isolation needs particular care, in order to avoid resonance effects. So, more future research is of utmost important to counter check the optimal isolation to be incorporated at different site condition.

`

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the effort by Bangladesh Earthquake Society as well as the grant RG093/10AET provided from the University of Malaya to fund the research work.

REFERENCES

Agarwal VK, Niedzwecki JM, Van de Lindt JW (2007). Earthquake induced pounding in friction varying base isolated buildings. Eng. Struct., 29: 2825-2832.

Ariga T, Kanno Y, Takewaki I (2006). Resonant behaviour of base-isolated high-rise buildings under long-period ground motions. Struct. Des. Tall Special Build., 15: 325-338.

Balkaya C, Kalkan E (2003). Nonlinear seismic response evaluation of tunnel form building structures. Comput. Struct., 81: 153-165.

Bangladesh National Building Code, BNBC (1993). Housing and Building Research Institute, Bangladesh Standard and Testing Institute.

Baratta A, Corbi I (2004). Optimal design of base-isolators in multi-storey buildings. Comp. Struct., 82: 2199-2209.

Bhuiyan AR, Okui Y, Mitamura H, Imai T (2009). A rheology model of high damping rubber bearings for seismic analysis: Identification of nonlinear viscosity. Int. J. Solids Struct., 46: 1778-1792.

Buckle I, Mayes RL (1990). Seismic Isolation: History, Application, and Performance—A World View. Earthquake Spectra, 6: 161-201.

Casciati F, Hamdaoui K (2008). Modelling the uncertainty in the response of a base isolator. Probabilistic Eng. Mech., 23: 427-437.

Clough R, Penzien J (1993). Dynamics of structures. 2nd ed., McGraw-Hill.

CSI Computer & Structures Inc. SAP2000 (2004). Linear and nonlinear static and dynamic analysis of three-dimensional structures. Berkeley (CA): Comp. Struct., Inc. SAP2000®.

Dall'Asta A, Ragni L (2006). Experimental tests and analytical model of high damping rubber dissipating devices. Eng. Struct., 28: 1874-1884.

Dall'Asta A, Ragni L (2008). Nonlinear behavior of dynamic systems with high damping rubber devices. Eng. Struct., 30: 3610-3618.

Deb S (2004). Seismic base isolation-an overview. Curr. Sci., 87: 1426-1430.

Di Egidio A, Contento A (2010). Seismic response of a non-symmetric rigid block on a constrained oscillating base. Eng. Struct., 32(10): 3028-3039.

Dicleli M, Buddaram S (2007). Comprehensive evaluation of equivalent linear analysis method for seismic-isolated structures represented by sdof systems. Eng. Struct., 29: 1653-1663.

Ebisawa K, Ando K, Shibata K (2000). Progress of a research program on seismic base isolation of nuclear components. Nuclear Eng. Des., 198: 61-74.

Habibullah A (2005). SAP 2000, Static and Dynamic Finite Element Analysis of Structures. Computers and Structures Inc., Berkeley, California.

Hong W, Kim H (2004). Performance of a multi-storey structure with a resilient-friction base isolation system. Comput. Struct., 82: 2271-2283.

Hussain RR, Saiful IABM, Ahmad SI (2010). Base Isolators as Earthquake Protection Devices in Buildings: VDM Publishing House Ltd. Benoit Novel, Simultaneously published in USA and U.K., p. 140.

Islam ABMS (2009). Evaluation of of Structural and Economic Implications of Incorporating Base Isolator as Earthquake Protection Device in Buildings in Dhaka [Master's Thesis]. Dhaka, Bangladesh: Bangladesh Univ. Eng. Technol., (BUET), p. 118.

Islam ABMS, Ahmad SI, Al-Hussaini TM (2010a). Effect of Isolation on Buildings in Dhaka In: 3rd International earthquake Symposium, BES; 5-6 March; Bangladesh, Dhaka, pp. 465-472.

Islam ABMS, Ahmad SI, Jameel M (2010b). Generation of Response Spectra Along With Time History for Earthquake in Dhaka for Dynamic Analysis of Structure. SUST Stud., 14(4): 56-68.

Islam ABMS, Ahmad SI, Jameel M, Jumaat MZ (2010c). Seismic Base Isolation for Buildings in Regions of Low to Moderate Seismicity: A Practical Alternative Design. Pract. Periodical Struct. Des. Constr., ASCE, [DOI: 10.1061/(ASCE)SC.1943-5576.0000093].
Islam ABMS, Jameel M, Jumaat MZ (2011a). Seismic isolation in buildings to be a practical reality: Behaviour of structure and installation technique. J. Eng. Technol. Res., Corrected Proof. 3(4):97-117.
Islam ABMS, Ahmad SI, Jameel M, Jumaat MZ (2011b). Study on corollary of seismic base isolation system on buildings with soft story. Int. J. Phys. Sci., In Press.
Ismail M, Rodellar J, Ikhouane F (2010). An innovative isolation device for aseismic design. Eng. Struct., 32: 1168-1183.
Jangid R, Datta T (1995). Performance of base isolation systems for asymmetric building subject to random excitation. Eng. Struct., 17: 443-454.
Jangid RS (2007). Optimum lead-rubber isolation bearings for near-fault motions. Eng. Struc., 29: 2503-2513.
Kelly TE (2001). Base isolation of structures: Design guidelines. Holmes Consulting Group Ltd.
Kelly TE, Robinson WH, Skinner RI (2006). Seismic Isolation for Designers and Structural Engineers: Robinson Seismic Ltd.
Kilar V, Koren D (2009). Seismic behaviour of asymmetric base isolated structures with various distributions of isolators. Eng. Struct., 31: 910-921.
Kim H-S, Roschke PN (2007). GA-fuzzy control of smart base isolated benchmark building using supervisory control technique. Adv. Eng. Softw., 38: 453-465.
Komodromos P (2008). Simulation of the earthquake-induced pounding of seismically isolated buildings. Comput. Struct., 86: 618-626.
Komodromos P, Polycarpou P, Papaloizou L, Phocas M (2007). Response of seismically isolated buildings considering poundings. Earthquake Eng. Struct. Dyn., 36: 1605-1622.
Komodromos P, Stiemer S (2001). Seismic isolation for earthquake resistant structures. Appl. Mech. Rev., 54: B112.
Loh C, Lin C, Huang C (1999). Time domain identification of frames under earthquake loadings. J. Eng. Mech., 126: 693.
Lu L-Y, Lin G-L (2008). Predictive control of smart isolation system for precision equipment subjected to near-fault earthquakes. Eng. Struct., 30: 3045-3064.
Matsagar VA, Jangid RS (2004). Influence of isolator characteristics on the response of base-isolated structures. Eng. Struct., 26: 1735-1749.
Micheli I, Cardini S, Colaiuda A, Turroni P (2004). Investigation upon the dynamic structural response of a nuclear plant on aseismic isolating devices. Nuclear Eng. Des., 228: 319-343.
Naeim F, Kelly J (1999). Design of seismic isolated structures: From theory to practice: Wiley.
Olsen A, Aagaard B, Heaton T (2008). Long-period building response to earthquakes in the San Francisco Bay Area. Bull. Seismol. Soc. Am., 98: 1047.
Ozbulut OE, Hurlebaus S (2010). Evaluation of the performance of a sliding-type base isolation system with a NiTi shape memory alloy device considering temperature effects. Eng. Struct., 32: 238-249.
Park K-S, Jung H-J, Lee I-W (2002). A comparative study on aseismic performances of base isolation systems for multi-span continuous bridge. Eng. Struct., 24: 1001-1013.
Pocanschi A, Phocas MC (2007). Earthquake isolator with progressive nonlinear deformability. Eng. Struct., 29: 2586-2592.
Polycarpou PC, Komodromos P (2010). Earthquake-induced poundings of a seismically isolated building with adjacent structures. Eng. Struct., 32: 1937-1951.
Providakis CP (2008). Effect of LRB isolators and supplemental viscous dampers on seismic isolated buildings under near-fault excitations. Eng. Struct., 30: 1187-1198.
SAP 2000 (2005), A general purpose Linear and Non-linear analysis program, Computers and Structures Inc., Berkeley, California.
Sharma A, Jangid R (2009). Behaviour of Base-Isolated Structures with High Initial Isolator Stiffness. Int. J. Appl. Sci. Eng. Technol., 5(3): 199-204.
Spyrakos CC, Koutromanos IA, Maniatakis CA (2009). Seismic response of base-isolated buildings including soil-structure interaction. Soil Dyn. Earthquake Eng., 29: 658-668.
Uniform Building Code, UBC (1997). Earthquake regulations for seismic isolated structures. Whitter (CA, USA).
Venancio-Filho F, Wang Y, Lin F, Claret A, Ferreira W (2001). Dynamic Analysis of Non proportional Damping Structural Systems Time and Frequency Domain Methods. Transaction, SMiRT 16, Paper No-1971, Washington DC.
Wilkinson S, Hiley R (2006). A non-linear response history model for the seismic analysis of high-rise framed buildings. Comput. Struct., 84: 318-329.
Win A (2008). Analysis and design of base isolation for multi-storeyed building. Proceedings in GMSARN International Conference on Sustainable Development: Issues and Prospects for the GMS, Asian Inst. Technol.,

`