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Seismic response variation of multistory base-isolated buildings applying lead rubber bearings

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Abstract. The possibility of earthquakes in vulnerable regions indicates that efficient technique is required for seismic protection of buildings. During the recent decades, the concept is moving towards the insertion of base isolation on seismic prone buildings. So, investigation of structural behavior is a burning topic for buildings to be isolated in base level by bearing device. This study deals with the incorporation of base isolation system and focuses the changes of structural responses for different types of Lead Rubber Bearing (LRB) isolators. A number of sixteen model buildings have been simulated selecting twelve types of bearing systems as well as conventional fixed-base (FB) scheme. The superstructures of the high-rise buildings are represented by finite element assemblage adopting multi-degree of freedoms. Static and dynamic analyses are carried out for FB and base isolated (BI) buildings. The dynamic analysis in finite element package has been performed by the nonlinear time history analysis (THA) based on the site-specific seismic excitation and compared employing eminent earthquakes. The influence of the model type and the alteration in superstructure behavior of the isolated buildings have been duly assessed. The results of the 3D multistory structures show that the lateral forces, displacement, inertia and story accelerations of the superstructure of the seismic prone buildings are significantly reduced due to bearing insertion. The nonlinear dynamic analysis shows 12 to 40% lessening in base shear when LRB is incorporated leading to substantial allowance of horizontal displacement. It is revealed that the LRB isolators might be potential options to diminish the respective floor accelerations, inertia, displacements and base shear whatever the condition coincides. The isolators with lower force intercept but higher isolation period is found to be better for decreasing base shear, floor acceleration and inertia force leading to reduction of structural and non-structural damage. However, LRB with lower isolator period seems to be more effective in dropping displacement at bearing interface aimed at reducing horizontal shift of building structure.

Keywords: seismic isolation; nonlinear behaviour; dynamic response; finite element analysis; lead rubber bearing; multistory building; ground excitation

1. Introduction

Due to the sudden and overpowering earthquakes, hazardous ground excitation can cause severe destruction to building structures. For the increase of seismic motions, there is need of increasing strength capacity of the building to sidestep the structural mutilation which might not be practical to continually increase indefinitely. The acceleration forces induced in high seismic zones may go beyond gravitational acceleration by one or even two times. Designing buildings to withstand such strength is neither easy nor cheap (Gharehbaghi *et al*. 2016, Wu *et al*. 2017, Faal and Poursha 2017). Although the earthquake itself is not manageable, its effect on buildings can be improved by averting the motion transmission from the foundation towards the superstructure using bearing isolation. Micheli *et al*. (2004) have shown a substantial reduction of seismic induced dynamic loads at structural base themselves when the structure is isolated. The isolation system provides additional flexibility as well as capability of energy dissipation by coming between the foundation and superstructure of the building (Ates and Yurdakul 2011, Ates 2012, Ismail *et al*. 2010, Ounis and Ounis 2013, Saha and Jain 2015, Zordan *et al*. 2014).

Several studies for the seismic retrofitting has focused on the incorporation of elastomeric bearings like Lead rubber bearing (LRB) isolation system in structural base (Islam *et al*. 2013a, 2013b). Jangid (2007), Providakis (2008) explored the earthquake induced responses of multi-story buildings base isolated (BI) by LRB under near fault motion. Such recent concept of base isolation for multi-story buildings is extended further (Islam *et al*. 2014, Islam *et al*. 2012b, Spyrakos *et al*. 2009). Pocanschi and Phocas (2007), Dicleli and Buddaram (2007), Casciati and Hamdaoui (2008), Islam *et al*. (2015) have reported on the advanced strategy to achieve the structural enhancement through isolation systems. Avossa and Pianese (2017) has investigated damping effects on the earthquake induced LRB isolated structures. Hu *et al*. (2017) has introduced a mechanical tension-resistant device for LRB. Fan *et al*. (2015) have addressed optimum design of LRB system with uncertainty parameters. The seismic performance of steel structures equipped with LRB has been assessed by Boumechra (2017), Ganji and Kazem (2017). Ozdemir and Gulkan (2016) has evaluated the scaling legitimacy for LRB

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isolated structures designed by means of bounding analysis. Chen *et al*. (2016) examined the performance and optimal design of seismic prone LRB isolated framed underground structures. This lead rubbing bearing isolation system might be a potential alternative than the complex and expensive approaches to increase the strength of structural element (Hosen *et al*. 2015, Rahman *et al*. 2017) as it offers reduction of element forces in a satisfactory manner.

Although the use of LRB isolators may be well known in many parts of the world, the practical implementation of these devices in the seismic prone buildings in Asia satisfying the local requirements, lacking apposite research is perceived. Bidirectional earthquake considerations have rarely been done. Time history methods have also not been dealt much in analyzing the isolated behavior of buildings. The response spectrum analysis, is somewhat speedy, succinct, and cheap to run. On the other hand, the time history analysis (THA) is comparatively time consuming, prolonged and expensive. Yet, the time domain scheme is incorporated when nonlinearities present in structural systems are considered. It has become easier than before to use the time domain method (Islam *et al*. 2012a, Oncu and Yon 2016, Sayin and Calayir 2015) due to advancements in computer software and hardware application.

As can be expected, there is a cost accompanying with the bearing device and therefore, it can merely be used when the benefits exceed the cost. The costing depends on structural size and reinforcement which relies on the structural responses. So, improvement of structural responses is targeted by using rubber bearing isolation devices at the structural base of buildings under actual site condition viz. the site-specific bi-directional earthquake data. The LRB models are adopted in order to explore the feasibility of this technique. A preliminary exploration of the suitability of incorporating isolators is done using equivalent static analyses. Dynamic analyses are carried out for different configurations of structures as well. Design parameters for the isolators of the buildings with varying number of stories are evaluated using SAP 2000 (CSI 2004). The displacement behavior, shear force, story inertia and floor accelerations of fixed base (FB) and BI buildings at different levels are assessed to get an idea of selecting potential lead rubber bearing system as well relying on the design requirements.

2. Materials and methods

2.1 Representative structures

The evaluations of representative building structures are projected to afford overall response characteristics for each type of system. The assessment technique employed is consistent in case of each building and LRB system which might provide judicious comparisons between systems. Four reinforced concrete (RC) buildings of 4,6,8 and 10 story @ 3.05 m c/c having squared plan size of 4 span @7.62 m c/c at both directions have been considered. The height of base (technical story) is 1.83 m.

The dead load excluding self-weight is 4.8 KPa whereas the live load is 2.4 KPa. The slabs have thickness of 150 mm. The exterior comer columns are 750 mm×750 mm, exterior middle columns are 950 mm×950 mm and interior columns are 1000 mm×I000 mm. The exterior and interior beams are 525 mm×825 mm and 600 mm×900 mm respectively. The chosen concrete compressive strength is 28 MPa and steel yield stress is 414 MPa. The fundamental time periods of the FB buildings are 0.5094s, 0.7547s, 0.7995s and 0.9945s for 4,6,8 and 10 story respectively. For the analysis, 5% damping i.e., critical damping ratio 0.05 has been chosen at the first natural frequency of the structure. Individual total seismic weight is presumed to be disseminated equally at all the floors. The RC buildings are moment resisting frames with the plan areas and elevations as shown in Fig. 1. In the finite element assemblage, the superstructure has been modeled as a linear elastic system. For FB buildings, the support conditions are fixed supports. The nonlinearities caused by seismic forces, base isolator and large deformation has been duly considered in the numerical analysis. Base isolators are designed and evaluated for every variation of selected building. The base isolators are assigned to the top of foundation and the bottom of the base mass.

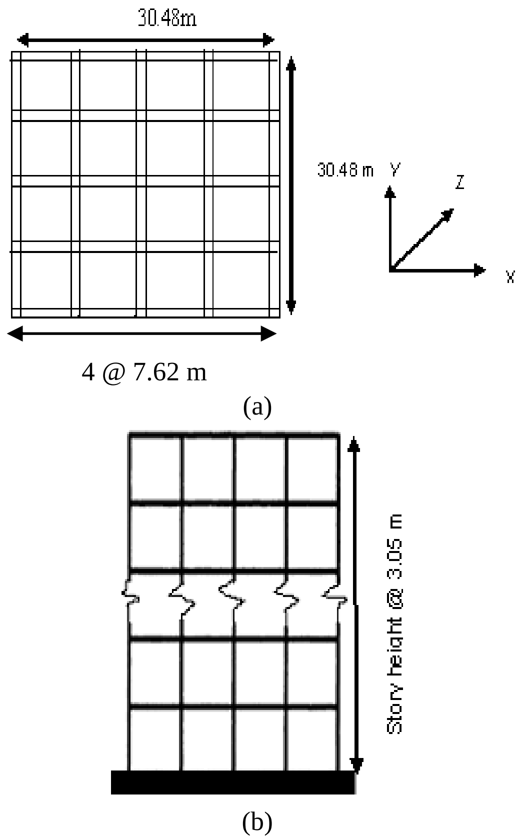


Fig. 1 Model of FB or BI multi-storied buildings: (a) Plan View, (b) Elevation

2.2 Design of LRB isolator

For this study lead rubber bearing isolators are designed with consideration for vertical loads, types of isolator and essential properties by means of MS Excel Spreadsheet tool, ISODES (Islam 2013a), formulated with equations and

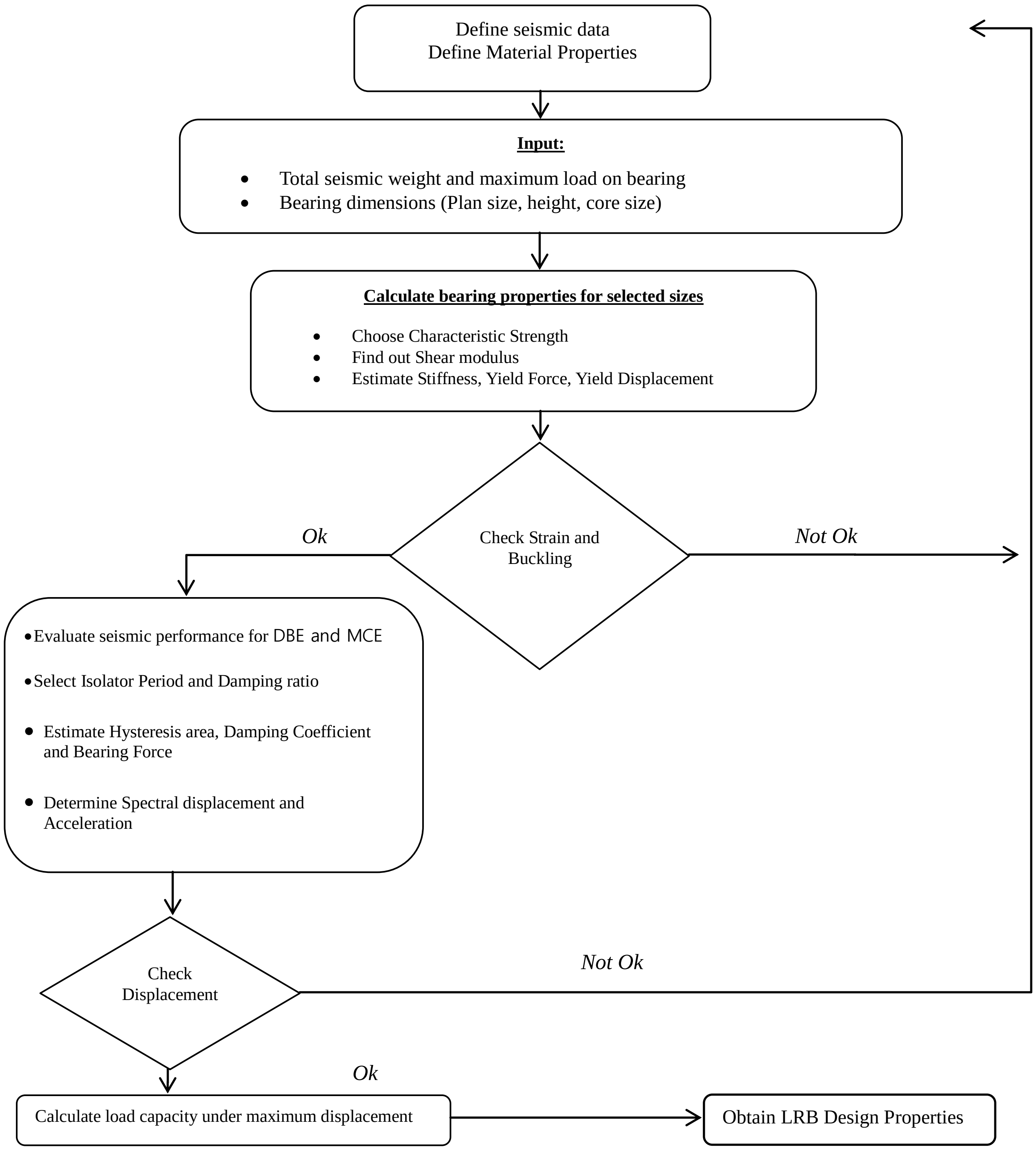
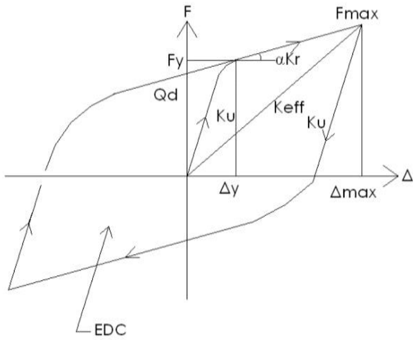


Fig. 2 Flow chart of LRB design algorithm

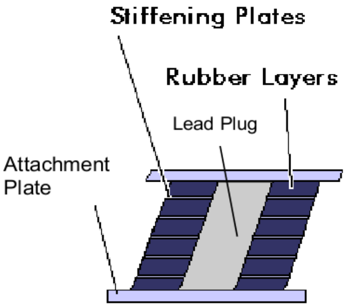
conditions. Fig. 2 displays flow charts for the sequential design of LRB isolators. The considerations are mentioned in the subsequent sections with proper evidence. The common properties of rubber chosen for designing the isolators are shear modulus: 400 KPa, ultimate elongation: 650% (Kelly *et al*. 2006), material constant: 0.87, and elastic modulus: 1350 kPa (Table 1). It is worth mentioning that the elastic modulus, ultimate elongation and material constant are functions of shear modulus. Damping is varied for the different isolators as mentioned in Table 2.

Lead rubber bearing (LRB) is assigned to all the internal and external column bases. Some iterations are needed as the performance of different isolator categories and layouts have been evaluated. For this present study, mentioned data types vary as per the type of isolator being assessed. Here, the variation of LRB types of isolators is considered.

The isolators have been defined by the size and shape of plan, configuration of rubber layer and size of lead core. Starting values are selected as per performance specifications and iteration is continued.



(a) Idealized force-displacement curve



(b) Deformation pattern

Fig. 3 Behavior of lead rubber bearing

2.2.1 LRB insertion

A lead rubber bearing comprises a lead plug put into a hole in a low damping elastomeric bearing. The lead plug is forced by the steel plates at out edge of bearing for deforming in shear and prevent the rubber compound from buckling. The nonlinear force deflection characteristics of the LRB device is modeled by bilinear hysteresis loop using characteristic strength, Q_d; yield displacement, Δ_y and post-elastic stiffness, K_r (Matsagar and Jangid 2004). Figure 3a shows an idealized hysteresis for LRB and Figure 3b represents its force-deformation behavior. The characteristic strength is defined by force intercept at zero displacement is a function of isolator yield strength like Eq. (1).

$$Q_d = \sigma_y A_{pl} \tag{1}$$

Where, yield strength, σ_y is subjected to the vertical load and lead core confinement. Eq. (2) and Eq. (3) offers the post-elastic stiffness and elastic stiffness (Kilar and Koren 2009) respectively.

$$K_r = \frac{G_\gamma A_r}{T_r} \tag{2}$$

$$K_u = 6.5 K_r \left(1 + \frac{12 A_{pl}}{A_r}\right) \tag{3}$$

The hysteresis loop area can be found from the expression in Eq. (4).

$$A_h = 4 Q_d \ (\Delta_m - \Delta_y) \tag{4}$$

2.3 Scheme of isolator usage

Table 1 Material properties used for isolator design

Elastomer Properties	Unit	Value
Shear Modulus	kPa	400
Ultimate Elongation	%	650
Material Constant	-	0.87
Elastic modulus	kPa	1350

For the present assessment, twelve variations of LRB isolation systems are employed. Each system has been designed satisfying the essential stiffness and strength properties as presented in Fig. 3. Here k_u and k_r denote elastic stiffness and yielded stiffness respectively, f_y expresses the yield force of Isolator.

Each isolation system is designed for 1.5, 2.0, 2.5 and 3.0 seconds' effective periods ensuring usual range of isolator period. The LRB variations have been premeditated for thee characteristic strengths, Q_d, as 0.05W, 0.075W and 0.010W. The effective damping is depending on Q_d and isolator period which ranges from 8% to 37% for the devices considered here. The variations of LRB properties and hysteresis parameters are presented in Table 2.

The design basis for LRB device considers site condition of S3 soil and the seismic zone of Z=0.15, according to the Uniform Building Code (UBC 1997). From the bi-directional seismic excitations, two levels of loading have been selected; the Design Basis Earthquake (DBE) for appraising the structural behavior and the Maximum Capable Earthquake (MCE) for estimating maximum displacements of LRB.

The hysteresis curves executed through the design procedure for the selected LRB variations for the multistory buildings specify bi-linear force deformation behavior reliant on elastic stiffness along with yielded stiffness.

2.4 Assessment technique

The prototype buildings have been evaluated increasing order of complexity by static and nonlinear time-history analyses. In designing LRB, an iterative process is conducted for the effective stiffness which is projected first as per the predicted displacements, and then adjusted according to the analyses results. The THA follow the usual procedure of its own. Following the analyses, the displacements and accelerations at each level are determined for every story which ultimately provide the displacements at isolator interface and base shears.

2.4.1 Static analysis

An equivalent linear static analysis has been carried out as a least complexity level. The lateral force from seismic effect are estimated selecting the factors Z, R, Soil Profile, etc. and wind induced lateral force using related coefficients. The progressions for seismic and wind analyses are taken from the code close to Uniform building code 1997 (UBC 1997). For the FB and BI building evaluation, a modification factor of R_I is considered as 8.0 and 2.0 respectively and the chosen importance coefficient is 1.0 as per occupancy category.

Table 2 Selected LRB system properties

System	Characteristic strength ratio with building weight, Q_d/W	Period of Isolator T_i (sec)	Damping β (%)
LRB1	0.050	1.5	8%
LRB1		2	11%
LRB1		2.5	15%
LRB1		3	20%
LRB2	0.075	1.5	13%
LRB2		2	20%
LRB2		2.5	26%
LRB2		3	31%
LRB3	0.100	1.5	20%
LRB3		2	28%
LRB3		2.5	33%
LRB3		3	37%

2.4.2 Dynamic analysis

The static analysis is beneficial for both the preliminary design of LRB and design review for certain conditions. Yet, the dynamic analysis is required for obtaining close structural behaviors and might be carried out in the form of THA.

2.4.2.1 Equation of motion

The motion equation of the building super structure remains same for each LRB variation which can be designated by the Eq. (5).

$$[M]\{\ddot{y}+\ddot{y}_b\}+[C]\{\dot{y}\}+[K]\{y\}=-[M][T_g]\{\ddot{y}_g\} \qquad (5)$$

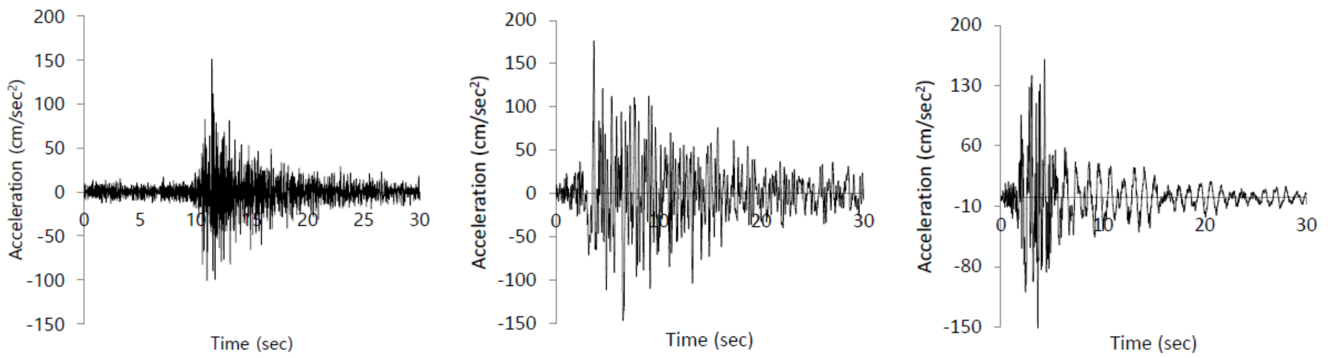
Where, $[M]$, $[C]$, and $[K]$ are the superstructure's mass, damping and stiffness matrices respectively matching with the degrees of freedom (DOF) at the floor slabs; $\{y\}=[y_x, y_y, y_z]^T$ is the displacement vectors at the slab associated with the base mass; $\{y_b\}=[y_{bx}, y_{by}, y_{bz}]^T$ is the base displacement vector allied to the ground; $\{\ddot{y}_g\}$ is the vector of ground acceleration and $[T_g]$ is the earthquake influence coefficient matrix.

2.4.2.2 Nonlinear time history analysis

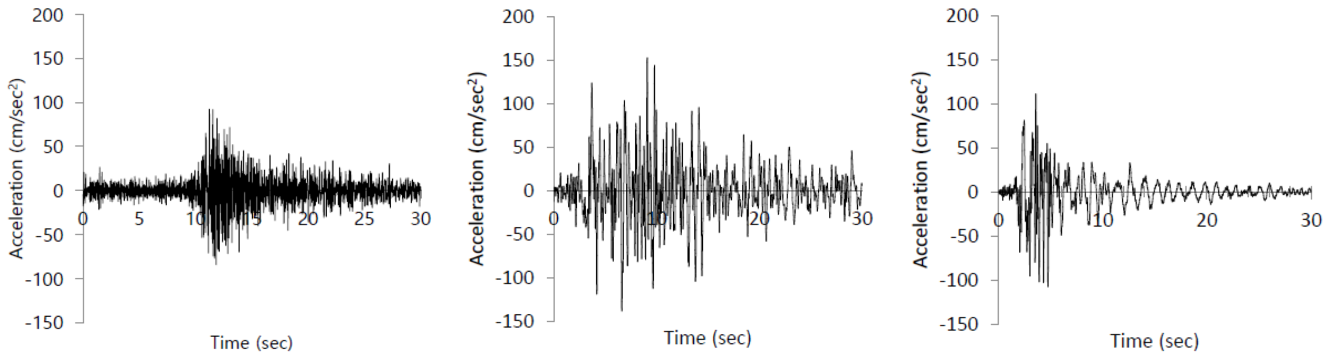
In the dynamic analysis like response spectrum method, the use of the modal superposition technique is pertinent for linear analysis merely (Wilkinson and Hiley 2006). To consider nonlinearities, time domain analysis is of utmost importance. Thus, a nonlinear THA has been carried out incorporating the selected time history of the ground excitation which resembles to the site condition of Dhaka (Fig. 4).

This earthquake record of Dhaka, Bangladesh, Longitude 90◦24' and Latitude 23◦43' has maximum acceleration in EW direction resembles to 0.154 g and 0.094 g in NS direction. The results have been compared with the structural response induced by other two seismic accelerograms. The 1952 Taft Lincoln School Tunnel record of July, 1952, Component N21E at the Kern Country, California denotes the peak acceleration 0.179 g and 0.117 g in EW and NS direction respectively.

The 2008 Pomona, California record of July, 2008 at 33.955◦N,117.765◦W in the Pomona & Chino Hills, Los Angeles, California Earthquake denotes the peak



(a1) Time History of Dhaka EQ in (EW) *X*-direction (b1) Time History of Taft EQ in (EW) X-direction (c1) Time History of Pomona EQ in (EW) X-direction



(a2) Time History of Dhaka EQ in (NS) *Y*-direction (b2) Time History of Taft EQ in (NS) Y-direction (c2) Time History of Pomona EQ in (NS) Y-direction

Fig. 4 Seismic time histories of selected Earthquakes (Islam *et al*. 2011)

Table 3 Design result of isolator dimensions

Bearing Dimension	LRB
Plan Diameter (mm)	850
Thickness of Rubber Layer (mm)	12.5
No. of Layers	16
Size of Lead Core (mm)	115
Shape	Circular
Total Height (mm)	280

Table 4 Summary of demand on LRB devices

		LRB	Comment
Gravity	Strain F.S.	3.34	$\varepsilon_u/\varepsilon$
	Buckling F.S	2.58	P_{cr}/P
DBE	Strain F.S.	1.65	$\varepsilon_u/\varepsilon$
	Buckling F.S.	1.86	P_{cr}/P
MCE	Strain F.S.	1.31	$\varepsilon_u/\varepsilon$
	Buckling F.S.	1.42	P_{cr}/P
Reduced Area/ Gross Area		0.778	At MCE=A_r/A_b

acceleration 0.185 g and 0.119 g in EW and NS direction respectively. The Taft and Pomona seismic time histories are shown in Fig. 4.

Each building model has been analyzed for each 30 second duration seismic record maintaining 0.005 seconds' time step. Furthermore, the P-delta effect has been deliberated to cope with the geometric nonlinearity. Direction integration has been performed using the Hilber-Hughes-Taylor Alpha method.

3. Validation

3.1 Validation of isolation system

All the structural time periods of FB buildings are ≤1.0 second which are considered as suitable values within reasonable limits (Kelly 2001, Kelly *et al*. 2006) to choose the option of base isolating. The building site allows horizontal displacements at base level within the range of 200 mm or more. Furthermore, the wind induced lateral loads (base shear) are less than 10% of the individual building weight as required (Deb 2004). Thus, isolators could be inserted at the structural base as an alternative to traditional FB design scheme.

The isolators' design parameters are shown in Table 3. Two conditions have been met before the performance of BI building could be evaluated. These two conditions are that the isolation bearings must be able to support the required loads safely and the overall performance of the LRB system should be satisfactory. The ability of isolation bearings to carry the loads is checked using the factors of safety (FS). As FS exceeded 1.0, the bearing ability to safely carry the loads is considered satisfactory. Table 4 condenses the status of LRB1 device with 1.5 sec. isolation period for prototype 10 story BI building with the factors of safety, which are within the recommended limits. The performance of the LRB system subjected to DBE and MCE is summarized in Table 5. The maximum (top) displacement

Table 5 Summary of seismic performance

	DBE	MCE	Comment
Effective Period T_D, T_M (second)	1.50	1.50	
Displacement D_D, D_M (mm)	98.04	183.14	
Force Coefficient V_b/W	0.190	0.327	S_a
Force Coefficient V_S/W	0.095		S_a/R_I
1.5×Yield Force/W	0.083		F_w/W
Wind Force/W	0.018		
Fixed Base V at T_D /W	0.025		
Design Base Shear Coefficient	0.073		S_a
Damping β_{eff} (%)	8.00	8.00	S_a/R_I
Damping Coefficient B_D, B_M	1.12	1.12	

value are well below the static isolator allowable design displacement 292.61 mm for a MCE level of ground excitation. This phenomenon is well maintained for all the BI building cases. Therefore, the properties of LRB system can be considered as reasonable.

3.2 Validation of structural responses

Basic model for combined isolation system of the authors have already been published (Islam *et al*. 2012a, Islam *et al*. 2013a). Similar building configuration has been chosen for the 10-story building as well as other seismic induced structure with identical environmental condition. The study extends the investigated as mentioned in detail to find out suitable alternative of lead rubber bearing system to be implemented in the structural base for getting better benefit.

4. Results and discussion

4.1 Appraisal of lateral shear at base

The key tools to investigate the dynamic responses of base-isolated buildings are the base shear, base displacements, inertia forces and floor accelerations. Among the building's performance parameters, an imperative response is the base shear coefficient which is basically maximum shear force at base normalized by the building weight.

The base shear coefficient values show ample lessening than no bearing condition when the LRB is installed. It indicated that the shear force at base obviously reduces substantially than the FB building design base shear 2365 kN due to the flexibility offered by bearings. The reduction ranges by 12% to 40% lower than the fixed base building shear coefficients. For the increase of building period the building flexibility affects more and thus the coefficient decreases. This is because of structural configuration together with the hysteresis behavior of the bearings.

The comparison of Dhaka earthquake induced responses with Taft and Pomona EQ for LRB 1 of 1.5 seconds' isolator period are presented in Fig. 5. It is observed that the base shear is higher by around 11% and 19% for Taft and Pomona earthquake respectively. The pattern of shear

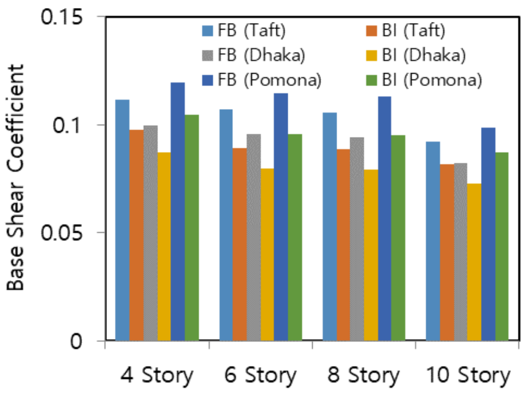


Fig. 5 Comparative base shear

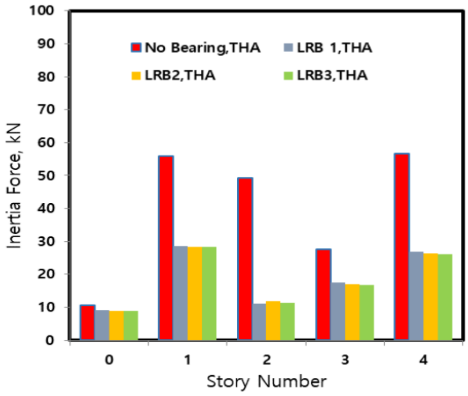


Fig. 7 Inertia Forces at 4 Story Building, *Ti*=1.5 sec.

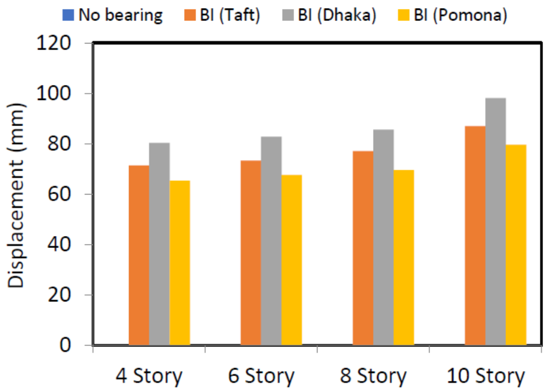


Fig. 6 Comparative base displacement

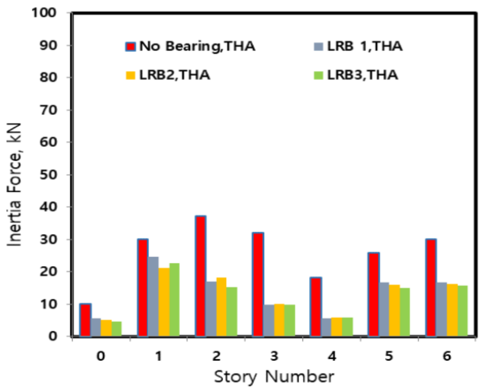


Fig. 8 Inertia Forces at 6 Story Building, *Ti*=2.0 sec.

variation is expected as per the intensity of maximum acceleration of these two seismic excitations.

4.2 Appraisal of displacement at bearing interface

For base isolated structures, displacement occurs almost uniformly in the whole upper structure and the displacement remains within acceptable limits. The relative displacement in between building floor levels is minimal, therefore, the structures can resist relatively high seismic tremors in a safe, economic and efficient manner against seismic ground excitation. For BI buildings, base displacement indicates the superstructure translation in isolation interface.

The relative variation of the displacements obtained are almost the similar. The maximum horizontal displacements at the base range from 96.01 mm to 107.70 mm for different bearings whereas the FB building has no movement at the base level because of the fixed foundation with superstructure. The variation of isolator displacement is around 11.22% due to the alteration of bearing properties. It is revealed that the lower displacements occur for those LRB cases which execute higher base shear. This eventually conform the preciseness of the study as escalation of lateral force restricts the extent of flexibility. The increment of period for the hysteretic systems leads to upsurge of displacement also conforming reduction of equivalent viscous damping. Fig. 6 plots the comparative maximum displacements from the earthquake history results for LRB1 of isolator period 1.5 seconds which provides a gradual trend of structural shift of 80.27 mm, 82.80 mm, 85.60 mm and 98.04 mm for the 4, 6, 8 and 10 story building respectively. Such expected and consistent manner of horizontal displacements reveal the precise assemblage of LRB isolated building structures. It is also observed that the outputs are relatively insensitive to the structural fundamental period.

The displacement of the superstructure at base level is zero for all the seismic time histories. However, for BI buildings, Displacements for Taft and Pomona earthquakes reduce by around 12% and 20% respectively. This is because of the less flexibility of superstructure controlled by higher lateral force at base. Such phenomenon indicates the accuracy of the dynamic scheme further.

Different kinds of LRB devices have dissimilar effects on displacement and shear force. The base shear coefficient and isolator displacement values for the 10-story building in case of 12 considered LRB systems are assessed under the Dhaka earthquake time history to see its selection satisfying the design requirements. It has been observed that the LRB1 systems with *Ti*=3.0 Seconds provide the least base shear coefficients. These are followed by the LRB2 and LRB3 sequentially as per reducing respective *Ti*. Most of the systems that have minimum base shear coefficients have relatively high displacements.

Moreover, the LRB1 systems of comparatively lower isolation periods show most efficiency at controlling bearing displacements. After these other LRB2, variations in lowest Ti followed by LRB3. Most of the LRB devices having minimum displacements offer somewhat high base shear and accelerations.

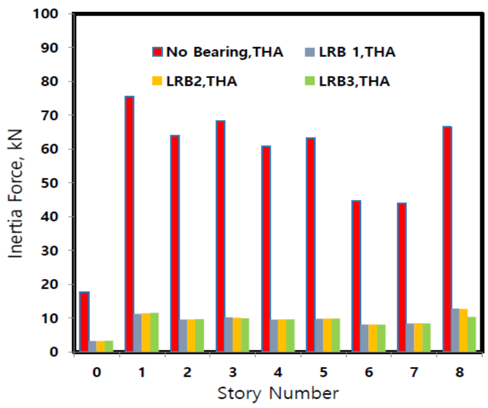


Fig. 9 Inertia forces at 8 Story Building, *Ti*=2.5 sec

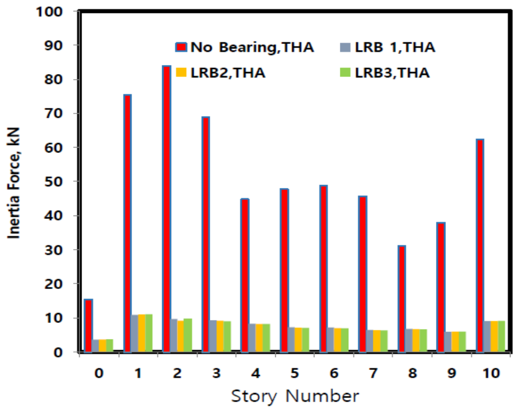


Fig. 10 Inertia forces at 10 Story Building, *Ti*=3.0 sec

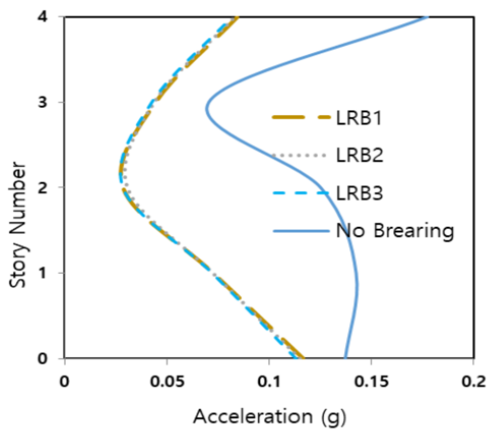


Fig. 11 Floor accelerations at 4 Story Building, *Ti*=1.5 sec

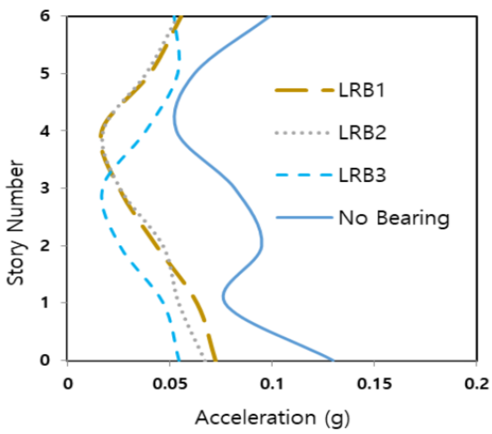


Fig. 12 Floor accelerations at 6 Story Building, *Ti*=2.0 sec

4.3 Appraisal of inertia force

For the fixed base structures, the tendency of inertia is to keep structures in place under the ground excitation offering in large displacements at different stories in structures. The distribution of these inertia forces along the building height defines the design shears in each story. Figs. 7-10 plot these distributions for four building configurations, each for one isolator effective period for BI cases with LRB.

There is a significant reduction of inertia force for LRB linked BI buildings than that parameter for the FB buildings. This is true for all the building configurations. The lessening of inertia is more significant with the increase of building height. However, trivial alteration of inertia for the respective building is observed due to the variation of LRB characteristic strength.

This consequence confirms the structural flexibility with safety offered by LRB. While the influence of LRB type on the inertia is compared one another, the higher the isolation period of LRB the lower the inertia forces of BI buildings.

4.4 Appraisal of floor acceleration

Lessening of seismic damage by inserting bearing device includes both the structural system as well as non-structural items like as building parts, components and contents. Therefore, a crucial significance in reduction of non-structural damage is the lessening of floor accelerations. Besides the maximum displacement of isolation systems and base shear coefficient, an important response indicator of base isolated buildings comprises story lateral force in superstructure. Therefore, the indicator is chosen as floor acceleration which can be treated as normalized inertia force as well.

Figs. 11-14 plots the floor acceleration distributions for different BI buildings in case of one effective isolator period as considered for inertia forces. The dispersal of the floor accelerations along building height outlines ultimately the lateral forces at every individual elevation together with the total overturning moments acting on the superstructure.

The floor accelerations for the FB building alters along the superstructure height, with a value of maximum ground acceleration at base level to significant values at the roof. Whereas for BI cases, the bottom level maximum accelerations increase towards top level maximum acceleration with relatively substantial reduced value and with inconsequential increment. Comparatively lower floor accelerations are observed for higher elevation buildings because of structural assemblage.

The salient behavior represents that the floor accelerations of BI models in all cases exhibit trivial change with height which agrees with the target of LRB insertion. The plots of maximum floor accelerations at different building elevations include the floor accelerations of FB building as a benchmark. The magnitude of the floor acceleration at elevation 0.0, ground level, is around 0.13 g

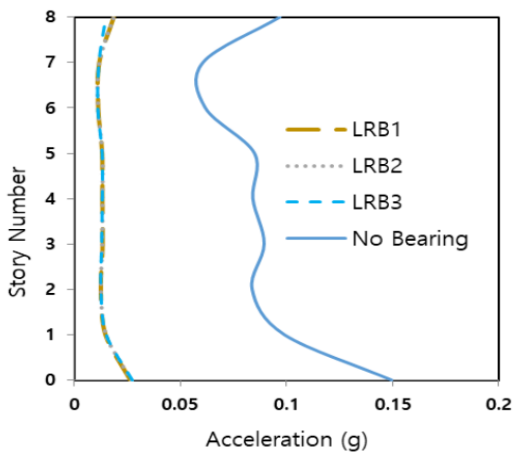


Fig. 13 Floor accelerations at 8 Story Building, *Ti*=2.5 sec

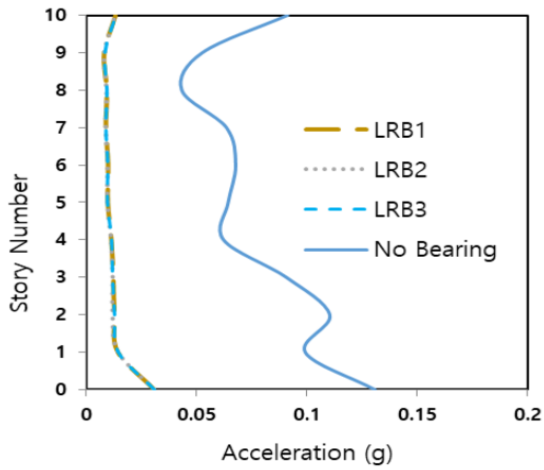


Fig. 14 Floor accelerations at 10 Story Building, *Ti*=3.0 sec

and it varies nonlinearly to upper floors for low rise building but comparatively identical with trivial deviations from first level for higher elevation structure. The major recognizable feature is that most LRB devices do not afford constant floor accelerations in fact for lower story, however, for higher story it shows expected identical pattern. The differences of the height-wise distribution of floor acceleration are more noticeable for low-rise buildings (4 and 6 story) possibly from the nonlinear effect of seismic excitation as well as structural system. This is reliant on the periods of vibration of these two buildings as well as the mass participation.

The BI buildings have three times period of vibration as around than FB respective buildings in first mode shape. Thus, the natural frequency associated with the building isolated by LRB is substantially lesser compared to the respective FB building frequency. In higher modes, the lower natural period persuades higher structural oscillations which increases the accelerations. The first mode maximum acceleration has been reduced to merely around one third. These first global modes for FB buildings are largely shaking modes whereas for LRB isolated structures they experience pure translation movements. The shift of period of vibration when LRB is incorporated ensures more flexibility.

5. Conclusions

The present study reveals that the lateral force, displacement, inertia and floor acceleration of the seismic prone buildings are significantly reduced due to incorporation of lead rubber bearing. The nonlinear dynamic analysis shows 12 to 40% decrease in base shear due to LRB insertion ensuring momentous horizontal shift of the superstructure at the base and inertia reduction. For isolated building, the inertia forces generally decrease in the upper floors with small amount. This phenomenon endorses the structural flexibility with safety obtainable by LRB. The reduction of floor acceleration for isolator are momentous that of no bearing cases. The bearing systems with comparatively high isolation periods shows most efficiency in controlling base shear. Furthermore, the least floor accelerations can be achieved by such LRB with lower characteristic strength and high isolation period. Similar behavior has been observed for inertia force as well. Thus, the isolators with lower force intercept but higher isolation period seems to be more suitable among the selected LRB types for lessening base shear, floor acceleration and inertia force which eventually leads to decrease structural and non-structural damage. However, for lessening of base shear, a concurrent rise in isolator displacement has been seen. The LRB systems with lower characteristic strength and relatively less isolation periods shows better productivity to minimize displacements in bearing face for dropping structural shift. Therefore, if the proper lead rubber bearing type be chosen as per the design requirement, potential benefit can be achieved from the LRB isolators for multistory building.

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