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Full Length Research Paper

Study on corollary of seismic base isolation system on buildings with soft storey

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Soft storey buildings are characterized by having a storey which has a lot of open spaces. This soft storey creates a major weak point in an earthquake. Since soft stories are classically associated with retail spaces and parking garages, they are often on the lower stories of a building, which means that when they collapse, they can take the whole building down with them, causing serious structural damage which may render the structure totally unusable. In this study, efforts have been given to examine the effect of incorporation of isolator on the seismic behavior of buildings subjected to the appropriate earthquake for medium risk seismicity region. It duly ensures incorporating isolator with all relevant properties as per respective isolators along with its time period and damping ratio. Effort has also been made here to build up a relationship for increasing storey height and the changes for incorporating isolator with same time period and damping ratio for both lead rubber bearing (LRB) and high damping rubber bearing (HDRB). Dynamic analyses have been carried out using response spectrum and time history analysis. Behavioral changes of structural parameters are investigated. The study reveals that the values of structural parameters reduce a large amount while using isolator. However, LRB is found beneficial than HDRB. The structure experiences huge storey drift at the soft storey level that may be severe and cause immature failure. The amount of masonry infill is very vital for soft storey buildings as its decrement increases reasonable displacements.

Key words: Soft storey, masonry infill, inertia force, floor acceleration, base shear, base moment, storey drift, failure prediction, base isolation, rubber bearing.

INTRODUCTION

If any building has a floor which is 70% less stiff than the floor above it, it is considered a soft storey building. While the unobstructed space of the soft storey might be aesthetically or commercially desirable, it also means that there is less opportunity to install walls to distribute lateral forces so that a building can cope up with the swaying characteristic of an earthquake. Seismic base isolation system has been rarely considered in research for buildings with soft storey. Increasing tendency of soft storey utilization is uncertain in context of structural feasibility in base isolated (BI) building. Through study in this concern is very burning matter, It may come as a surprise that these rubber foundation elements can actually help to minimize earthquake damage to buildings, considering the tremendous forces that these buildings must endure in a major quake. Unlike the conventional design approach, which is based on 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). Seismic isolation separates off the structure from the harmful motions of the ground by providing flexibility and energy dissipation capability through the insertion of the isolated device so called isolators between the foundation and the building structure (Ismail et al. 2010). Invention of lead rubber bearing (LRB, 1970's) and high damping rubber bearing (HDRB, early 1980's) gives a new dimension to the seismic base isolation design of BI structure (Islam, 2009; Hussain et al. 2010). Significant amount of both past and recent research in the

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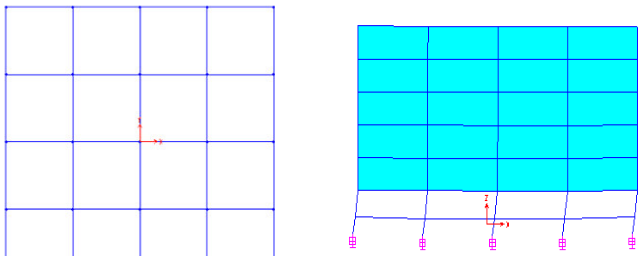

Plan Elevation

Figure 1. Plan and elevation of modeled building with soft bottom storey.

neighborhood of base isolation has focused on the use of elastomeric bearings, such as HDRB and LRB and their effects on buildings (Islam and Ahmad, 2010; Islam et al., 2010a). Jangid (2007) and Providakis (2008) investigated seismic responses of multi storied buildings for near fault motion isolated by LRB. Dall' Asta and Ragni (2006, 2008) and Bhuiyan et al. (2009) covered experimental tests, analytical model and nonlinear dynamic behavior of HDRB. Islam et al. (2010b) concentrated on study of base isolation at low to medium risk seismicity region. Although it is a relatively recent technology, seismic isolation for multi storied buildings has been well evaluated and reviewed (Barata and Corbi, 2004; Hong and Kim, 2004; Matsagar and Jangid, 2004; Komodromos, 2008; Lu and Lin, 2008; Spyrakos, 2009; Polycarpou and Komodromos, 2010). Islam et al. (2011a) investigated the practical reality of seismic base isolation system and their installation technique. Optimal base isolation system has been explored for multi-storey buildings in low to medium seismic risk vicinity Dhaka, Bangladesh by Islam et al. (2011b). Base isolator with hardening behavior under increasing loading has been developed for medium-rise buildings (up to four storeys) and sites with moderate earthquake risk (Pocanschi and Phocas, 2007). Nonlinear seismic response evaluation was performed by Balkaya and Kalkan (2003). Resonant behavior 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). Ebisawa et al. (2000), Deb (2004), Dicleli and Buddaram (2007), Casciati and Hamdaoui (2008) and Di Egidio and Contento (2010) have also given effort in progresses of isolated system. Yoshimura (1997) have done the nonlinear analysis of RC building with soft storey collapsed by 1995 Hyogoken-Nanbu earthquake. Mo and Chang (1995) dealt with application of base isolation thought and its modification (Chen and Constantinou, 1990) to building with soft first storey. Chen and Constantinou (1992) introduced the use of teflon sliders regarding advancement of the soft first storey concept. Wilson (2002), Komodromos et al. (2007) and Kilar and Koren (2009) focused the seismic behavior and responses through dynamic analyses of isolated buildings. Kirac et al. (2010) and Wilbowo et al. (2010) have done the failure and collapse modeling analysis of weak storey building.

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 Bangladesh especially medium risk seismicity region like Dhaka as per the local requirements. On the other hand, Bidirectional earthquake consideration which is also a very burning matter has been rarely done. Yet again, Time history and response spectrum methods were rarely dealt simultaneously for buildings concerning isolated behaviors. The time history method is relatively more time consuming, lengthy and costly. The response spectrum analysis, on the other hand, is relatively more rapid, concise, and economical. However, time domain method has been employed for considering nonlinearities present in the structural systems. Nowadays, it is more convenient using time domain method compared to past advancing of computer's hardware and software. Combined model of HDRB and LRB have been adopted here to explore the feasibility. Preliminary exploration for suitability of incorporating isolator has been done with equivalent static analysis. Then dynamic analysis has been performed to satisfy the structural limitation executing different comparative contribution. The analysis and design of Isolators for a sample 6-storied residential building in Dhaka using SAP 2000 was performed first. Design parameters of isolator for this building and several buildings varying number of stories have been evaluated. Static analysis has also been performed along with dynamic analyses. The displacement behaviors for fixed and isolated buildings were discussed at different levels. Base shear and overturning moments were also compared for the cases. Finally net cost savings through using isolator for this building and several buildings varying number of levels have been evaluated.

Here the structural implications have been investigated for incorporation of isolator on the seismic behavior of buildings subjected to the appropriate earthquake for Dhaka region, Bangladesh using isolator with properties as per needed for respective maximum loaded column. Some buildings for square in plan and of different storey with soft bottom storey have been analyzed to present its action in structural behavior change.

MATERIALS AND METHODS

Prototype building with soft bottom storey

For this study a prototype building of plan size 4@7.62 m span at both directions has been chosen for 6 storeys with soft bottom storey (Figure 1) along with varying percentage of infill. It was first analyzed for different bearing properties. And then taking the same plan the building has also been analyzed for 3, 4 and 5 storey to build up some important relation which is shown subsequently. For all the buildings dynamic analysis for both response spectrum and time history analysis have been performed.

Table 1. Masonry infill properties.

Parameters	Values with unit	Comment
Compressive strength	f"m = 7.5 MPa	Mix proportion 1:4
Modulus of elasticity	Em = 5625 N/mm^2	750*f'm
Shear modulus	G = 2250 N/mm^2	0.4*Em
Unit weight	γ =18.85 KN/m^3	

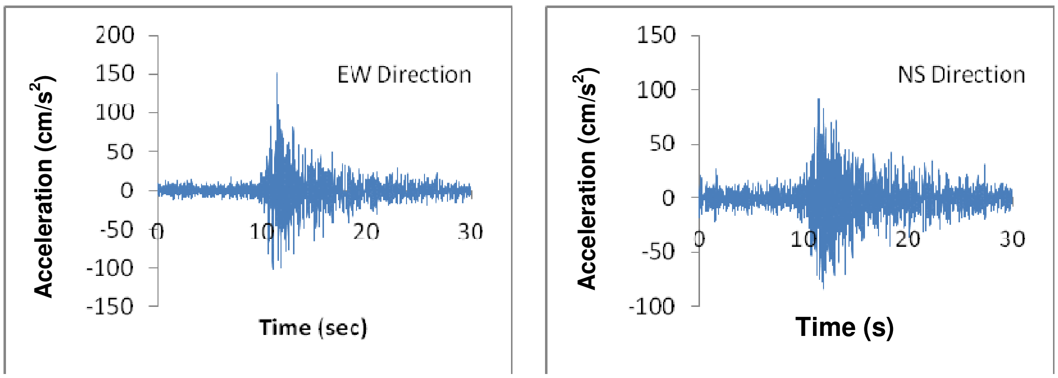

Figure 2. Selected time history for Dhaka EQ.

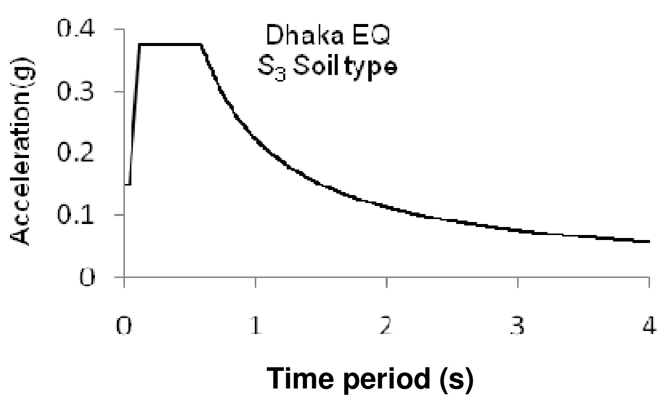

Figure 3. Response spectrum for Dhaka EQ.

Masonry infill properties

Masonry walls were introduced in the buildings to upper stories of first storey to make the structure soft storey at bottom floor. All the walls are defined in SAP program as Shell element of 10" thick brick wall. Brick wall properties are shown in Table 1.

Isolator properties

Here the evaluations is intended to provide overall response characteristics of building with soft storey for lead rubber bearing and high damping rubber bearing system. A total of 4 variations of LRB and HDRB were used for the evaluation. The designs (Kelly, 2001; Kelly et al., 2006) were completed using the Excel spreadsheet which implements the design procedures as per UBC, 1997. The design basis includes S_3 type soil profile for Dhaka having seismic zone coefficient, Z = 0.15 and beyond 15 kms of a Type A fault (BNBC, 1993). The most recently occurred Natore Earthquake (Islam et al., 2010c) which is nearest of Dhaka region has been properly scaled to produce the desired earthquake load for buildings in Dhaka. Time history and corresponding response spectrum for 5% damping is shown in Figures 2 and 3 respectively for this record. This is the design basis earthquake (DBE) which is used to evaluate the structural 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 2 lists the variations considered in the evaluation and the hysteresis parameters used for modeling.

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 structural parameters at each level has been saved and then processed to provide further study. SAP 2000 (CSI, 2004; Habibullah, 2005) is found to be suitable to conduct the dynamic analyses.

Table 2. Isolation system variations.

System title	Characteristic strength (Q_d)	Period of isolation (s)	Initial stiffness, K_1 (KN/mm)	Post-yield stiffness, K_2 (KN/mm)	Yield force, Fy (KN)
LRB1	0.050	2	12.20158	1.11331	328
LRB2	0.075	2	12.20158	1.11331	492
LRB3	0.100	2	12.20158	1.11331	656.1
HDR	--	2	10.97653	2.45166	223

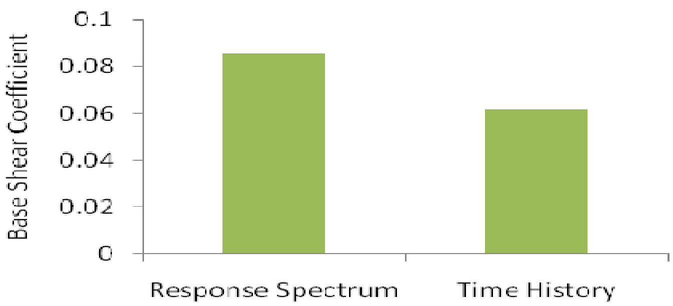

Figure 4. Base shear coefficients for LRB1 Ti = 1.5 s.

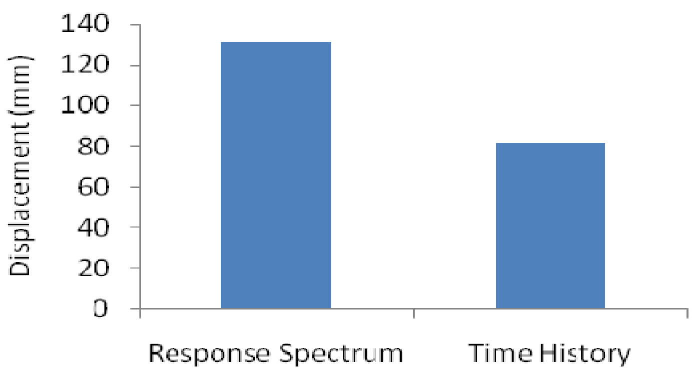

Figure 5. Displacement for LRB Ti=1.5 s.

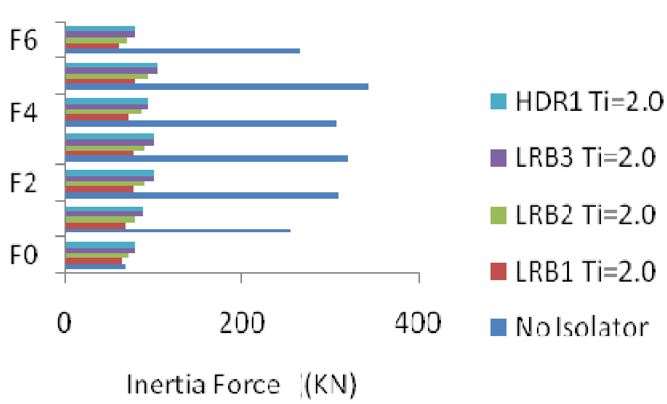

Figure 6. Response spectrum inertia force at different floors for 6 storey BI building.

OBSERVATION AND RESULTS

Parametric study for 100% masonry infill

Base shear

The response spectrum results comparing with time history results are plotted in Figure 4 for the lead rubber bearing (LRB 1) with a period of 1.5 s. Base shear coefficients (Figure 4) at time history is 26% lower than the response spectrum base shear value.

Displacement

The displacement from the time history analysis plotted in Figure 5 is about 34% lower than the displacement from response spectrum analysis. Figure 5 suggests that results are relatively insensitive to the period of the structure above the isolators.

The mean time history results show that the design procedure generally provided a conservative estimate of isolation system performance except for the elastic isolation system, where the design procedure under-estimated displacements and shear forces, especially for short period isolation systems.

Building inertia force

The isolation system response provides the maximum base shear coefficient that is the maximum simultaneous summation of the inertia forces from all levels above the isolator plane. The distribution of these inertia forces of the structure defines the design shears at each level and the total overturning moments on the structure.

Response spectrum inertia force in Figure 6 shows that the inertia force distributions for the buildings without isolation demonstrate an approximate linear increase with height, compared to a uniform building with no devices. The fixed base buildings have an inertia force at the base level. This is because a rigid spring was used in place of the isolation system for these models and the base mass was included.

The inertia forces for time history analysis are shown for the building comparing with different bearing case (Figure 7). The distribution shows lower values in lower

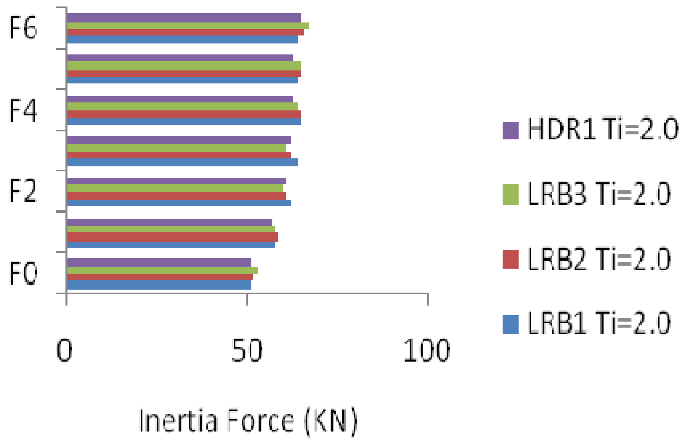

Figure 7. Time history inertia force for 6 storey BI building.

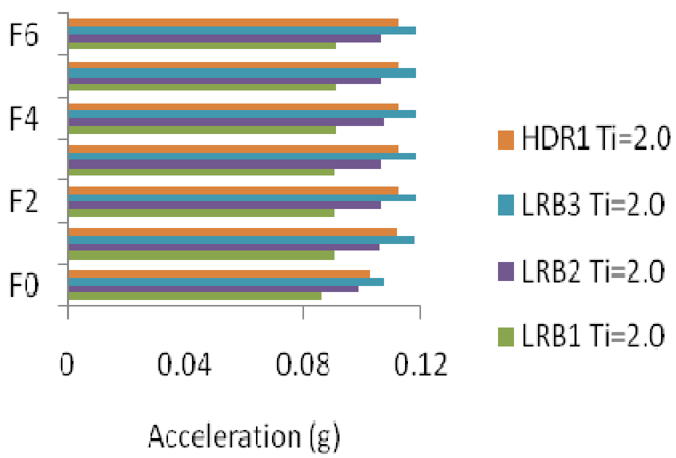

Figure 8. Response spectrum floor accelerations for 6 storey BI building.

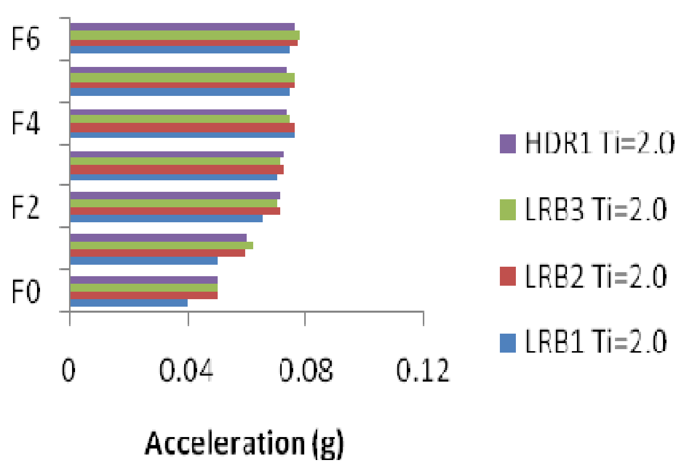

Figure 9. Time history floor accelerations for 6 storey BI building.

floor and tends to increase at upper.

Floor acceleration

Reducing earthquake damage by seismic isolation includes not only the structural system but also non-structural items such as building parts, components and contents. Of prime importance in attenuating non-structural damage is the reduction of floor accelerations.

The floor acceleration from the response spectrum analysis is proportional to the floor inertia forces, as shown in Figure 8. The accelerations for the building without devices increase approximately linear with height, from a base level equal to the maximum ground acceleration (0.107 g) to values 1.25 times this value at the roof 0.134 g. The isolated displacements always are lower than the 0.154 g ground acceleration and exhibit almost no increase with height.

Plots of maximum floor accelerations from time history results for the building configurations are provided in Figure 9. These are the same building and isolation system configurations for which the inertia forces are plotted in Figure 7. All plots are the maximum values from the time history analysis. The acceleration at elevation 0.0, ground level, is 0.054 g. The most obvious feature of the plots is that most isolation systems do not provide the essentially constant floor accelerations developed from the response spectrum analysis in Figure 8.

Effect of masonry infill variation on structural parameters

For this investigation two types of isolator are chosen to ease the effective comparison. The effects are compared for both LRB and HDRB with isolator period Ti = 2.0 s and damping = 16%. The masonry infill was also varied for 83% and 100%. The results described are the governing result through response spectrum analysis. For 83% masonry infill Inter storey drifts are shown in Figure 10. At later behavior change for masonry infill variation are shown. Storey drifts have peculiar characteristics. For first storey it shows a larger value and for the immediate storey, inter storey drift falls 44~50% for LRB and 48~60% for HDRB (Figure 10). Percentage of infill on structure changes the behavior of different parameters. Here values for 83% masonry infill are compared with 100% infill shown in Figure 11 as inter storey drift.

Displacement, shear, moment behavior of soft storey building for varying number of storey

Here the soft storey building of plan described previously are analyzed for different storey considering isolator time period Ti = 2.0 and Damping = 16% for both LRB and HDRB. Comparative data are summarized graphically in

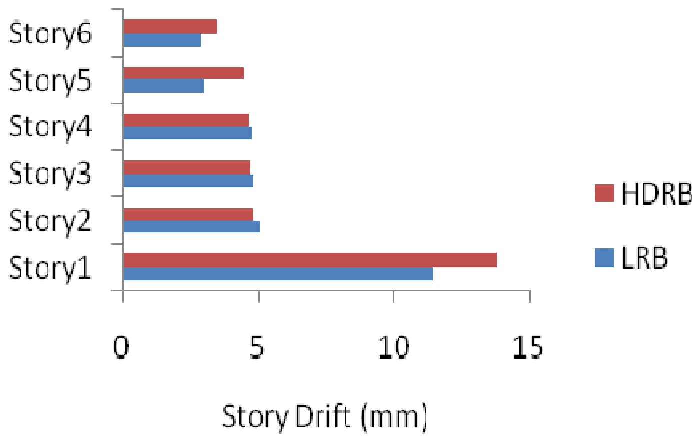

Figure 10. Storey drift of 6 storey BI building (Response spectrum analysis).

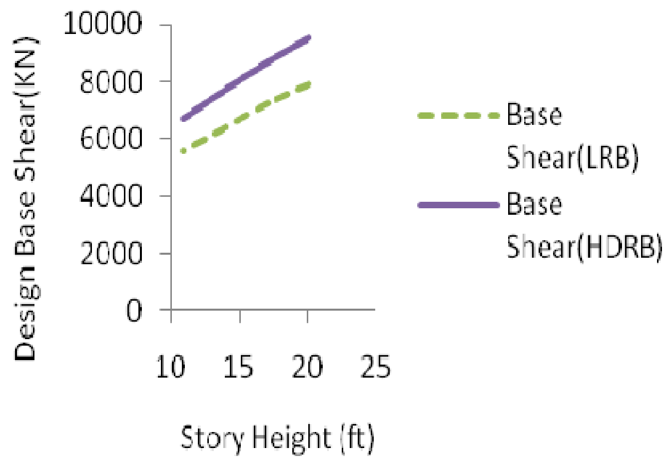

Figure 13. Design base shear with height for LRB and HDRB at soft storey BI building.

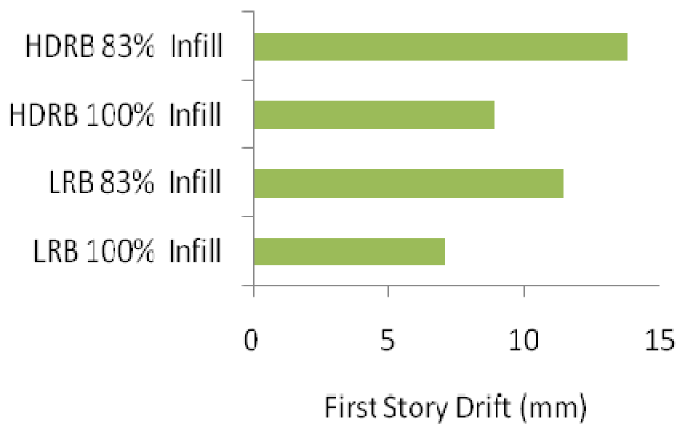

Figure 11. First storey drift of 6 storey BI building for varying Infill (Response spectrum analysis).

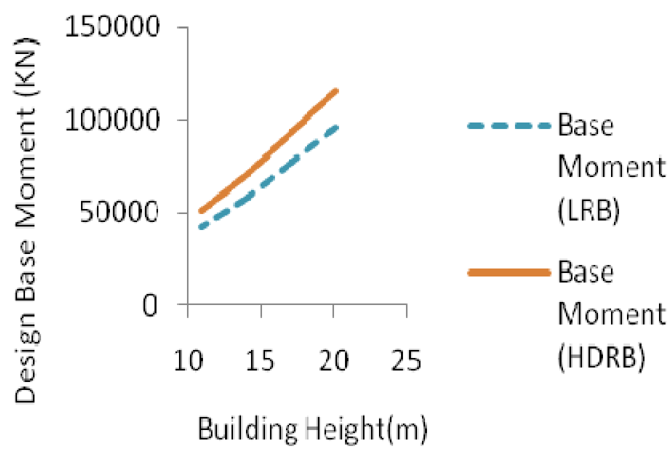

Figure 14. Design base moment with height for LRB and HDRB at soft storey BI building.

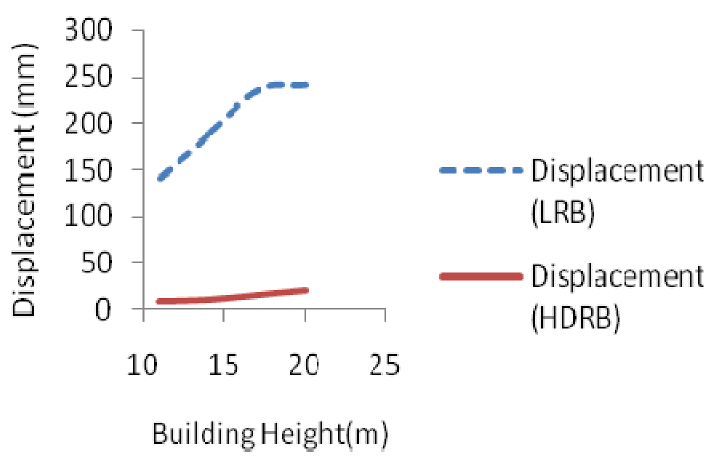

Figure 12. Top storey displacement with height for LRB and HDRB at soft storey BI building.

Figures 12, 13 and 14. LRB acknowledges amount of displacements that are significantly greater than HDRB case. Apart from this design base shear for LRB case is 20~25% less than those of HDRB linked buildings. This trend is identical for all the buildings. Following the same fashion, base moments are 15~20% lower than the buildings isolated by HDRB. These are reasonable considering the flexibility exerted by respective isolation system. It is also desirable that with increasing number of storey, the top displacement, base shear and base moments also increase.

DISCUSSION

Storey drifts have peculiar characteristics. For first storey it shows a larger value and for the immediate storey, inter storey drift falls 44~50% for LRB and 38~48% for HDRB.

Again for decreasing the masonry infill percentage from 100 to 83%, storey drift increases up to about 50%. For same value of damping and isolator period LRB shows less value of design forces that is, base shear and base moment 20~25% than HDRB. The rate of increment of these forces is of steep slope. The isolated displacements for LRB are greater than those of HDRB. Response spectrum analysis shows the larger displacements. The floor accelerations from the response spectrum analysis are proportional to the floor inertia forces, as the accelerations for the building without devices increase approximately linear with height, from a base level where the maximum ground acceleration is very low (≈0) to the roof (0.134 g). These values always are lower than the peak ground acceleration and exhibit almost no increase with height. Again for time history analysis the accelerations in the building with no isolation the acceleration at Elevation 0.0, ground level, is the peak ground acceleration, which is constant at 0.054 g. For lead rubber bearings (LRB) as the period of the isolator increases, the accelerations decrease. As the building period increases the short period isolators show some amplification with height but this is slight. And the accelerations are highest for the shortest isolated periods. The HDRB provide different distribution of acceleration than LRB. As the period of the isolators increases, the accelerations increase here. And the accelerations are highest for the longest isolated periods. On the other hand, for reduction of infill amount increases the displacement in a significant amount.

Conclusions

In building structures, soft storey subjects a major weak point in earthquake, and may cause severe change in structural behavior which may render the structure totally unusable. In this revise, effect of incorporation of isolator on the seismic behavior of buildings subjected to the appropriate earthquake for Dhaka has been evaluated. The values of structural parameters reduce in a drastic amount while using isolator. With increasing time period the acceleration is also increased for HDRB which is clearly reverse for LRB. Apart from this, incorporation of lead rubber bearing (LRB) is beneficial than high damping rubber bearing (HDRB). Of course the suitability of isolation system may vary as per time period, damping and specific design constraint. It is also shown that the amount of masonry infill is very vital for soft storey buildings. Decreasing infill quantity increases the structural responses in a reasonable amount.

In this study, HDRB and LRB are incorporated for investigation. Other isolation devices can also be adopted to justify the structural behavior. 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. Different variations of infill characteristics can also be given in utmost important in research for its outstanding effect.

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