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DESIGN OF RC BUILDING WITH LRB ISOLATOR AS PER BNBC 2020 PROVISIONS

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ABSTRACT

Bangladesh is in a high-risk earthquake zone geographically. Although earthquake prevention is impossible, earthquake damage can be minimized. A base isolation system can be utilized to mitigate the extent of earthquake damage. A rubber pad is utilized as an isolator in the base isolation system to absorb the energy produced by ground shaking. In this research a 10-story fixed base building was modelled, analyzed, and designed using ETABS (ver.17.0.1) considering the building location at seismic zone 2 (Dhaka). For this study Bangladesh National Building Code (BNBC) 2020 was followed regarding loading condition. The same building was modelled, analyzed, and designed using Lead-Rubber Bearing (LRB) isolator. One of the major objectives of this study was to design the LRB isolator considering BNBC 2020 provisions. Three different isolators were designed for central, external, and internal position of the building based on normal forces acting on the bottom of the building. The comparison of the time before and after the installation of the LRB isolator was shown in this analysis. The moment due to earthquake load was found to be reduced by up to 65% for corner columns, 70% for external columns, and 75% for internal columns. The fundamental period for building without an isolator varied from 2.88 seconds to 0.00009 seconds. The period for the same building with a lead-rubber bearing (LRB) isolator, on the other hand, varied from 4.858 seconds to 0.035 seconds. The increment in time-period due to use of LRB isolator ensured the flexibility against earthquake. The parametric study of same building in different seismic zone was also included in this research. Moment reduced by 30-70%, 45-50%, 25-30% for seismic zone 2, 3, and 4 respectively. Rebar percentages were also reduced by 30-40%, 30-35%, 25-30% for seismic zone 2,3, and 4 respectively. Base shear was found reduced by 49.3 percent and time- period was found increased by 68.7 percent.

Keywords: *Earthquake, Base-isolation, Rubber-bearing, ETABS, BNBC 2020*

1. INTRODUCTION

The location of tectonic plates affects earthquakes. Bangladesh is in a tectonically active zone, close to the two plate boundaries known as the Indian plate and the Eurasian plate. In the east and north of Bangladesh, the Indian and Eurasian plate borders meet. The collision of the Indian and Eurasian plates is the source of regular earthquakes in Bangladesh (BNBC 2020, Part-VI, Chapter-2). Historically, building have been isolated from input earthquake energy by putting a layer of sand, or steamed rice between the base of the building and the soil, as observed in some historical buildings in China and Japan. In modern engineering practices, devices for vibration isolation or dissipation of input energy were applied. In structural engineering, flexible rubber blocks have been used to isolate buildings. (Naeim et al., 1999). So, base isolation technique is developed to mitigate the transmission of ground motion due to earthquake into the superstructure of a building. In this technique building is separated from its base using base isolation system which provides earthquake resistance. It provides flexibility at the base in the horizontal direction and introduction of dampers absorbs energy. Seismic isolation separates 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 (Islam, et al., 2010). Historically Bangladesh has been affected by five earthquakes of large magnitude of 7 or greater than 7. In recent years, the occurrence and damage caused by several earthquakes which has magnitude between 4 and 6 inside the country or near the country's border, has raised an alarm. (BNBC, 2020, Part VI, Chapter 2, Section 2.5). The capital city Dhaka is vulnerable to the earthquake as the country is in an active region. According to seismic zoning map prepared by BUET, it can be said that 43 percent area of Bangladesh are at high-risk zone, 41 percent at moderate and 16 percent at low-risk zone. Reduction of horizontal force that generated from earthquake, is the main concern for the designers. To construct building in such active seismic zone like Bangladesh, base isolation system is the most suitable solution because it mitigates the lateral forces and provide flexibility. In this study a 10-story hospital building made of RC will be analysed following BNBC 2020, one with fixed base i.e., without isolator and other with isolated using Lead-Rubber Bearing (LRB) for several case studies to identify the effectiveness of the base isolation in different seismic situations. Islam, Ahmad, and Jameel (2011) revealed simplified design procedures for LRB and HDRB for multi-stored buildings in Bangladesh. Islam, Ahmad and Hussaini (2016) found that LRB has been demonstrated to be more successful at reducing individual floor acceleration and thereby nonstructural damage.

2. METHODOLOGY

In this study, a 10-story hospital building made of RC was analysed and designed without isolator using equivalent static analysis method considering the design parameters for Dhaka region. This study also described the differences between the seismic behaviour of the hospital building with and without LRB isolator. Specifications given in BNBC 2020, Part VI, Chapter 2 was used for design of the building. For the design of Lead-Rubber Bearing (LRB) isolator, seismic isolation provisions from the Bangladesh National Building Code, 2020 was used as well as formula from Naeim et al. (1999) was also used.

2.1 Description of the Building

A 10 storied hospital building made of RC, with 4 bays of 8 m in each direction, the story height is 3 m and bottom story height is 4 m, as shown in Figure 1. The building was modelled using ETABS (ver. 17.0.1). In this model two materials were used, steel and concrete. Property of concrete: Modulus of Elasticity, E = 24,700 MPa, Poisson's Ratio, U = 0.2, Specified Concrete Compressive Strength, fc' = 27.6 MPa. Property of steel: Modulus of Elasticity = 200,000 MPa, Minimum Yield Strength = 414 MPa, Minimum Tensile Strength = 621 MPa. Two cases of buildings were considered here: (i) Building with fixed base (ii) Base-isolated with LRB isolator.

2.2 Loads on Building

All structures need to be designed to resist both gravity forces and lateral forces. In this study considered loads are gravity loads (dead load and live load) and lateral loads (earthquake load and

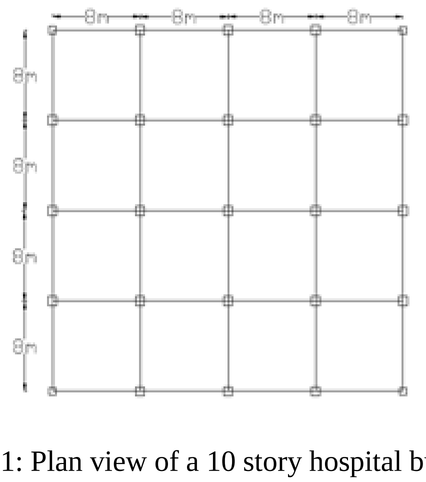

Figure 1: Plan view of a 10 story hospital building

wind load). Load from partition wall and floor finish was considered 1.92 kN/m^2 and 1.4 kN/m^2 respectively, which are dead load. For hospital building minimum uniformly distributed load was used 3.80 kN/m2 according to BNBC 2020, Part VI, Chapter 2.3. Regarding wind load, basic wind speed for Dhaka city was considered 65 ms^{-1}.

2.2.1 Earthquake Loads

Minimum design earthquake forces were determined according to BNBC 2020, part VI, Chapter 2, section 2.5. For this study site class SC was considered which indicates that soil profile up to 30 m depth has a deep deposition of dense or medium dense sand, gravel, or stiff clay according to Table 2.5.1, BNBC 2020. The building considered in this study is located at Dhaka. So as per Table 2.5.2, BNBC 2020 seismic zone is 2 where seismic intensity is moderate and seismic zone coefficient, Z= 0.2.

2.2.2 Response Spectrum

Design response spectrum represents the earthquake ground motion for which the building need to be designed. Following BNBC 2020 (Part VI, chapter 2) the spectral acceleration was obtained using the following equation—

$$S_a = \frac{2}{3} * \frac{ZI}{R} C_S$$

Here, Z= Seismic zone coefficient, I= Importance factor, which depends on occupancy category of the building. The building was used for this study falls in the occupancy category IV and importance factor need to be considered 1.5. Seismic design category for this building is D. SDC was selected based on seismic zone 2, site conditions SC and occupancy category IV as per Table 2.5.6, BNBC 2020. Response reduction factor was considered 8 for Special reinforced concrete moment (SMRF) frame. C_S = Normalized acceleration response spectrum, which is a function of building period and site class. Building period was calculated using the following formula:

$$T = C_t (h_n)^m = 0.0466 * (31)^{0.9} = 1.025 \text{ sec} > T_c = 0.6 \text{ sec}$$

The value of C_t and m was obtained from Table 2.5.8, BNBC 2020 for concrete moment resisting frame. For soil type SC the value of S, T_B, T_C and T_D is obtained 1.15, 0.2, 0.6, 2.0 from Table 2.5.4 BNBC 2020. For $T > T_c$, $C_s = 2.5 * S * \eta * (T_C/T) = 2.5 *1.15 *1*(0.6/1.025) = 1.683$

Spectral acceleration, $S_a = \frac{2}{3} * \frac{ZI}{R} C_S = \frac{2}{3} * \frac{0.2*1.5}{8} *1.683 = 0.0421$

Spectral acceleration was then used for calculating design earthquake. In this study the analysis was done by the response spectrum curve for soil type SC and damping ratio 0.05. Response spectrum function for 5% damping is shown in Figure 2.

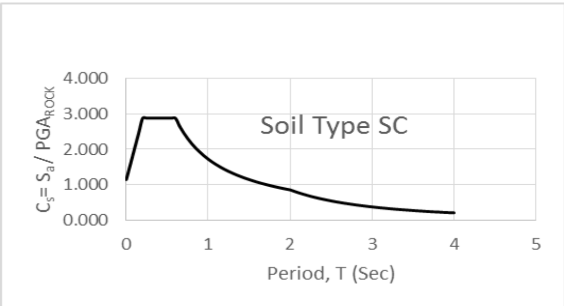

Figure 2: Response Spectrum Curve for Dhaka EQ (0.2g) (BNBC 2020, Part VI, Chapter 2, Section 2.5)

2.3 Analysis of the Building

The hospital building that located in Dhaka was modelled using ETABS and then it was analysed with two sets of modifiers. So, two analyses were done using ETABS. One was for serviceability check-for service load combination and another one for strength adequacy check- for ultimate load conditions. In this study strength design method was used. So structural members would have strength to resist the most unfavourable effect of the combinations of factored loads. For this study following load combinations were used that described in BNBC 2020, Part VI, Chapter 2, (sec 2.7.3.1). For strength check ACI 318-08 was selected as design code, which is like BNBC 2020. Appropriate modifier as mentioned in BNBC was used for beam, column, and slab. For beam. Bending modifier for beam was used M11 = M22 = M12 = 0.01. In case of frame element beam property modifier for torsion, I22 and I33 was considered 0.35. And for frame element column the value of property modifier I22 and I33 was used 0.7. For serviceability condition check new set of modifiers were used. Bending modifier for slabs remain same as 0.01. According to BNBC 2020 section 6.6.3.2.2 to calculate immediate lateral deflection a 1.4 times moment of inertia need to be used. So, for frame element beam stiffness modifier were used 0.5 and for column it was 0.7. Serviceability condition required check for wind sway, wind drift and seismic drift.

Wind sway check required a load combination which is D + 0.5 L + 0.7 W. For this study the height of the building is 31 m,

Maximum wind sway = (1/500) * H
= (1/500) * 31 m
= 0.062 m = 62 mm

From ETABS analysis maximum deflection for new load combination was observed 17.043 mm > 62 mm. So, the hospital building was serviceable under wind sway condition.

According to BNBC 2020, Part VI, Chapter 1, section 1.5.6 Story drift limitation are:

$$\Delta \leq 0.005h \text{ for } T < 0.7 \text{ second}$$
$$\Delta \leq 0.004h \text{ for } T \geq 0.7 \text{ second}$$

In this study the hospital building has a period of 1.025 sec > 0.7 second. So, the maximum value of story drift for this study could be 0.0008. From ETABS analysis the value of maximum story drift for wind was observed 0.0008 << 0.004. From ETABS analysis the value of seismic drift was observed 0.01 considering C_d = Deflection amplification factor = 5.5 for special reinforced concrete moment frame and I = Importance factor for hospital = 1.5. According to BNBC 2020 Table 6.2.21 allowable drift limit for occupancy category and all other structure is 0.01. It was observed that the building in this study was also serviceable considering seismic story drift. After checking strength and serviceability of the building following sections were finalized.

Table 1: Column Dimensions (Before installation of isolator)

	Bottom 5 Story	Top 5 Story
Corner Column	550 mm X 550 mm	550 mm X 550 mm
External Column	680 mm X 680 mm, 750 mm X 750 mm	680 mm X 680 mm
Internal Column	1000 mm X 1000 mm	700 mm X 700 mm

2.4 Isolator Design

Following equations were used to calculate different parameters and geometric properties of the LRB isolator:

$K_{eff} = \left(\frac{2 * \pi}{T_D}\right)^2 * \frac{W}{g}$ ......(1)

$W_D = 2\pi\, K_{eff}\, D_D^2\, \beta_{eff}$ ......(2)

$K_{eff} = K_r + \frac{Q}{D}$ *and* $W_D = 4Q*(D-D_y)$ ......(3)

Neglecting D_y, first approximation for Q, $Q = \frac{W_D}{4D}$ ......(4)

$K_2 = K_{eff} - \frac{Q}{D}$ *and* $K_1 = 10\, K_2$ ..... (5)

The area of the lead plug is required was calculated by dividing Q with 10. Design philosophy for lead plug is that they should not be too slender or too square. The total rubber stiffness K_r is given by,

$K_{Eff(R)} = K_{Eff} - \frac{Q}{D}$ ..... (6)

Area of Bearing, $A_{LRB} = \frac{K_{Eff(R)} * t_r}{G}$ ..... (7)

Diameter of bearing, $D_{LRB} = \sqrt{\frac{4A_{LRB}}{\pi}}$ *mm* ..... (8)

Shape factor, $S = \frac{1}{2.4} * \frac{f_v}{f_h}$ ..... (9)

Thickness of Single layer of rubber, $t = \frac{D_{LRB}}{45}$ mm (Rounding to nearest 5 mm)

Total height of LRB, h = 2 * End plate thickness + Thickness of shim plate * n + N * t

Following characteristics were considered for the design of the lead core rubber isolator as mentioned in table 2 and table 3.

Table 2: Structure Features

Number of floors	**10**
Total Building Height, H	31 m
Floor Height	3 m
Column Dimensions	As mentioned in Table 1
Beam Dimensions	400 mm X 700 mm
Material Information	
Concrete	27.6 MPa
Reinforcing steel	414 MPa

The building is located in Dhaka where earthquake magnitude is moderate, so seismic source type was considered C sources for isolator design. According to BNBC 2020, Part VI, Chapter 2 zone factor is 0.20 so, it is in the zone 2. For this analyses damping coefficient was considered 5 percent. For LRB isolator design target period = 3 sec, Critical Damping Ratio = 5%, Shear Modulus = 0.7 N/mm^2, Yield Strength of Lead = 10 MPa, Maximum Shear Strain = 100%, Bulk Modulus = 1000 MPa were considered. The main isolator properties used in this hospital building as specified in the following table 4 which need to be used for defining link properties in ETABS.

Table 3: Seismic Properties of the Subject Structure According to BNBC

Seismic Source Type	**C**
Distance to Known Source Fault (km)	> 15 km
Seismic Zone coefficient, Z	0.2
Site Soil Profile Type	SC
Near Source Factors, Na	1
Near Source Factors, Nv	1
Spectral Seismic Coefficient, CA	0.23
Spectral Seismic Coefficient, CV	0.345
Damping Coefficient	5

Table 4 : Isolator Parameters to be used in the subjected structure below Interior column

Property	**Values**
Rational Inertia, I	0.013
U1 Effective Stiffness	1240000
U2 & U3 Effective Stiffness	1240
U2 & U3 Effective Damping	0.05
U2 & U3 Distance from End J	0.002
U2 & U3 Stiffness	12400
U2 & U3 Yield Strength	35

2.4.1 Geometric Properties of Isolator

In this study three full scale lead rubber prototype isolators of a past project were used subjected to high speed testing with three fully reversed cycle. The details of the isolators are illustrated in Figure 3. The isolator has a total rubber thickness, t_r =0.3 m, a bonded rubber area, A_{rub} = 2.286 m^2, a lead core area, A_p = 2560 mm^2, and a shape factor of S = 10. Following tables 5 shows the design parameters for isolator.

Table 5: LRB Design Parameters

	Internal	**External**	**Corner**
Edge of the Bearing	25 mm	20 mm	25 mm
Total height of the bearing	526 mm	140 mm	225 mm
Number of rubber layers	10	8	6
Thickness of individual layers	15 mm	10 mm	10 mm
Diameter of lead core	57 mm	40 mm	40 mm
Number of steel plates	9	7	5
Thickness of steel plates	2.8 mm	2.4 mm	2.4 mm
Thickness of top and bottom cover plate	25 mm	25 mm	25 mm

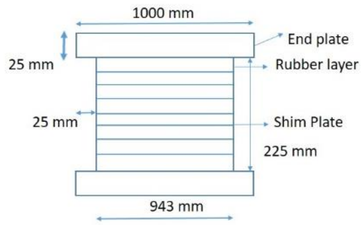

Figure 3: Lead-Rubber Isolator Unit Details (Below Corner Column)

2.5 Modelling of the Building (Lead-Rubber Bearing based)

The same hospital building located at same region was modelled using Lead-Rubber Bearing (LRB) at the base of the building using ETABS (ver. 17.0.1). All the parameters were same as mentioned for the building with fixed base in previous section except the base restraint and building period. For change in period of the building the definition of earthquake load would also change. New period for base isolated building will be the time period from modal analysis of base analysis building is 2.88. For defining earthquake load in ETABS following parameters were provided,

- Base shear coefficient, S_a = 0.010
- Building height exp. K = 2.19

2.6 Analysis Procedure

In this study used analysis procedure for both the fixed based and LRB based model was response Spectrum Analysis (RSA) which is a type of Linear Dynamic Analysis. Response spectrum analysis was used to determine the total design displacement and total maximum displacements. For response spectrum analysis firstly, modal analysis was required. To define response spectrum function, BNBC 2020, Part VI, Chapter 2 was used. Load case was also named response spectrum where a scale factor is used. The scale factor was = (I * g)/R = (1.5 * 9.81)/8 = 1.84 for acceleration in the vertical direction and for UY and UZ direction scale factor was used 30 percent and 60 percent of 1.84 respectively. Damping value was used 0.05, which is assumed constants for all modes. After strength check and serviceability check of the LRB based hospital building final column dimensions were obtained as shown in table 6, after designing and repeated revision of the column and beam sections. The story drift for a LRB based isolated building was calculated same as fixed base building. In this case story drift for earthquake load was observed 0.012 considering importance factor 1 and C_d = 5.5 for special reinforced concrete moment resisting frame system. This observed value was within allowable limit. For strength and serviceability check of the LRB based building previously mentioned procedure was used (Section 2.3).

3. RESULT ANALYSIS

In this study a 10 story RC hospital building was analysed and designed to get the column and beam dimensions considering the rebar percentage approximately 4 percent or below.

3.1 Column Dimensions

In this study it was observed that the column dimensions can be reduced after using Lead-Rubber Bearing (LRB) isolator in the same building located in Dhaka region. In case of every column the dimensions was reduced by 50 - 70 mm in each direction. Response spectrum analysis was used to determine the total design displacement and total maximum displacements. For response spectrum analysis firstly, modal analysis was required. For modal analysis a modal case was defined in ETABS, where Ritz vector was used as modal case sub type. Ritz vectors were recommended for response spectrum because this formulation is computationally efficient only pertinent mode shapes which occur in the horizontal plane are identified. For modal analysis mass source need to be defined. Table 6 shows the variations in column dimensions between when isolator is not used and when LRB isolator is used.

Table 6: Variations in column dimensions before and after of LRB isolator installation

	Without LRB Isolator		**With LRB Isolator**	
	Bottom 5 Story	**Top 5 Story**	**Bottom 5 Story**	**Top 5 Story**
Corner Column	550 mm X 550 mm	550 mm X 550 mm	350 mm X 350 mm	480 mm X 480 mm
External Column	750 mm X 750 mm	680 mm X680 mm	500 mm X 500 mm	500 mm X 500 mm
Internal Column	1000 mm X 1000 mm	700 mm X 700 mm	650 mm X 650 mm	600 mm X 600 mm

3.2 Time Period

For the 10-story hospital building mode numbers were considered was 30. For this study it was observed the fundamental period for building without isolator varies in the range of 2.88 second to 0.00009 second. On the other hand, for the hospital building with lead-rubber bearing (LRB) isolator, period with isolator varied in the range of 4.858 second to 0.035 second. After installation of LRB isolator the period of the building increased approximately 70 percent. So, the increment in period with the use of base isolator indicated that the effect of resonance of earthquake cannot affect the building with LRB isolator. Figures 4 and 5 shows the fundamental period and mode shape for both the building without isolator and with isolator respectively.

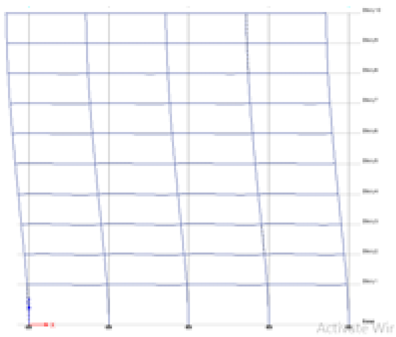

Figure 4: First mode, T = 2.88 sec (Without LRB Isolator)

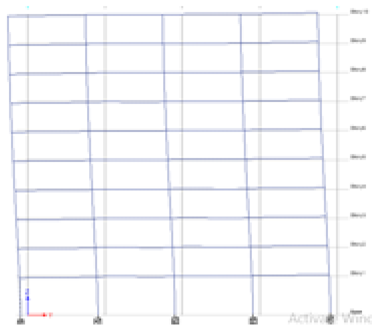

Figure 5: First mode, T = 4.858 sec (With LRB Isolator)

3.3 Column Moment

From these analyses it was observed that column moment value was reduced for hospital building with LRB isolator comparing to hospital building without isolator. From fixed base building i.e.,

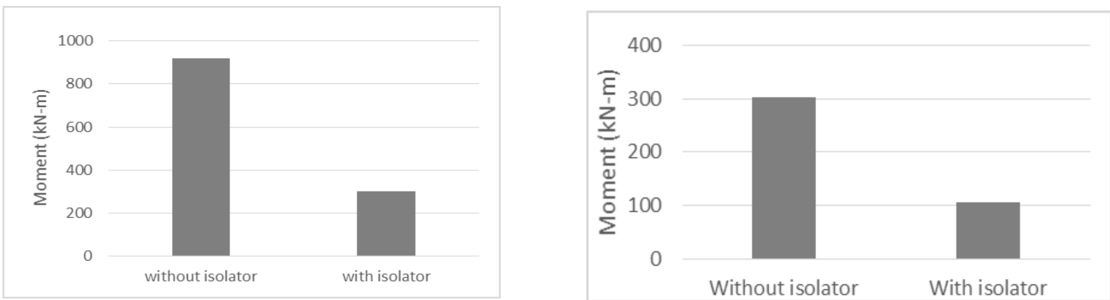

Figure 6: Maximum moment for earthquake load (External column & Corner column)

building without isolator corner column maximum moment was observed 302 kN-m, whereas from building with LRB isolator maximum column moment was observed 106 kN-m. So, building with LRB isolator reduce corner column moment approximately 65 percent. Figures 6 and 7 shows the variations in external and corner column moment which was obtained after Response spectrum analysis.

3.4 Story Shear & Story Drift

After response spectrum analysis the value of story shear for both the fixed base and Lead-Rubber Bearing (LRB) was obtained. Figure 7 shows the variation in story shear before and after installation of LRB isolator. It shows that when response spectrum analysis was done in X direction then the value of story shear for building with LRB isolator decreased when compared to building without isolator. The value of story shear for bottom story was obtained 10442 kN and 6730 kN for fixed base building and isolated building using LRB respectively. This story shear value indicated that use of LRB isolator decrease the story shear value approximately 36 percent. The value of story shear for top story was obtained 3500 kN and 1340 kN for fixed base building and isolated building using LRB respectively. This story shear value indicates that use of LRB isolator decrease the story shear value approximately 62 percent. So, it can be said that the story shear reduced gradually more as the story increased from bottom to to 10th story.

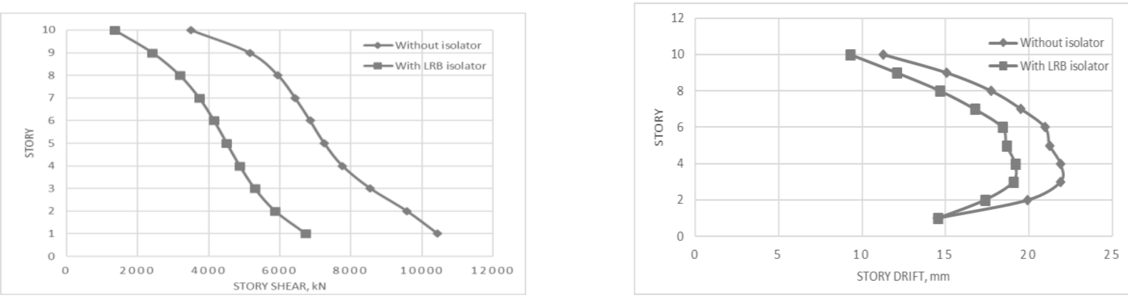

Figure 7: Story shear and Story drift for response spectrum analysis in X and Y direction

Figure 7 shows the variation in story drift after response spectrum analysis is done in both X and Y direction. For fixed base building story drift at bottom story is obtained 14.5 mm and for isolated building with LRB is obtained 14.5 mm. So, there was no significant difference in story drift value when we are considering lower story. For fixed base building story drift at top story is obtained 11.25 mm and for isolated building with LRB is obtained 9.3 mm. So, as number of stories increased the value of story drift decreased in case of isolated building using LRB. The difference between story drift can decrease approximately 18 percent. So, the decrease in story drift in higher stories indicates that the building will be strong against earthquake.

3.5 Base Story

In this study, the value of base reaction after response spectrum analysis the value of base shear for both the fixed base and Lead-Rubber Bearing (LRB) was obtained. Figures 8 and 9 shows the variation in base reaction difference between hospital building with isolator and without isolator. For response spectrum analysis in X direction, the value of base shear in building which has a base fixed with ground was obtained 9700 kN. Analysis in X direction the value of base reaction in building which has LRB isolator in bottom of every column. From the differences between in base reaction it can be concluded that the value of base shear reduced by 50 percent when LRB isolation was installed at the bottom of the column. Again, response spectrum analysis was done in Y direction also. From this analysis, the value of base reaction was obtained for fixed base building is 20650 kN and for isolated building with LRB was 10470 kN. So, the value of base shear reduced approximately 50 percent when Lead-Rubber Bearing (LRB) was installed which indicates that the building remains stable against earthquake. It has been observed for both case that the value of base shear for base isolated building was more compared to fixed base building. This is because of the distribution of mass and stiffness which made the fundamental time period more than 1 sec.

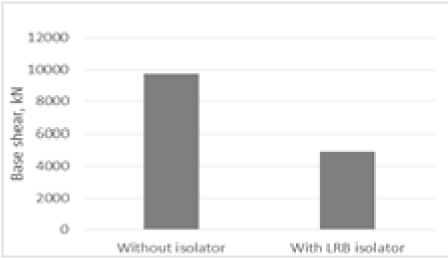

Figure 8: Base shear in X-X direction

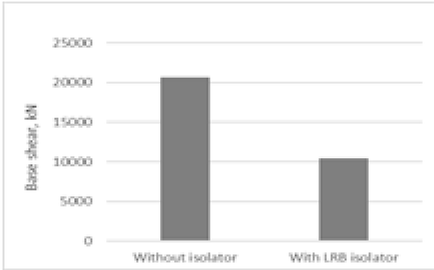

Figure 9: Base shear in Y-Y direction

3.6 Comparison of column moment and rebar percentage for different seismic zone

From this study it can be said that base shear percentage increase, when same building was moved to higher seismic zone. Table 7 shows that in every zone rebar percentage reduce as LRB isolator was installed in every different seismic zone. In zone 2 rebar percentage reduce by 30 to 40 percent. In case of zone 3 the reduction in rebar percentage was reduced to 30 to 35 percentage. In case of zone 4 the reduction in rebar percentage was reduced to 25 to 30 percent.

Table 7: Variation of rebar percentage in different seismic location

	Zone 2	**Zone 3**	**Zone 4**
EQ Load	0.0421	0.06	0.08
Wind speed, m/s	65.7	80	61.1
Moment Reduction	30-70 percent	45-50 percent	25-30 percent
Rebar Percentage reduction	30-40 %	30-35 %	25-30 %

4. CONCLUSION

In this study it was found that base shear, story shear, story drift, column moment, rebar percentage reduce with the use of LRB isolator. On the other hand the value of time period increase which indicates the flexibility of the structure. After an extensive and systemic study, the following conclusions applicable only for this building: The design procedure of base isolator used in this study can be used effectively for any other building. In this study it is obtained that column moment reduced by 30 to 70 percent. Base shear reduced by 49.3 percent in case of zone 2. Story shear gradually reduce as we increase story from bottom story to top story. Time period increase by 68.7 percent. In case of zone 3 moment reduction percentage is 45 to 50 percent and rebar percentage reduction percentage is 30 to 35 percent. In case of zone 4 moment reduction percentage is 25 to 30 percent and rebar percentage reduction percentage is also 25 to 30 percent. This study also conclude that LRB isolator can be used for retrofitting of any existing building which was designed with only gravity load.

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