Malaysian Journal of Civil Engineering 28(2):257-269 (2016)

PERFORMANCE OF REINFORCED CONCRETE HOSPITAL BUILDING SUBJECTED TO EARTHQUAKE USING BASE-ISOLATION SYSTEM

Md. Abul Hasan*

Department of Disaster & Environmental Engineering, Faculty of Civil Engineering, Chittagong University of Engineering & Technology, Chittagong-4349, Bangladesh

*Corresponding Author: *hasanrazu0601056@gmail.com,*

Abstract: The frequent occurrence of earthquake in the Bangladesh and up-gradation of seismic design code (BNBC-1993) has heightened the need for investigation of seismic performance of existing lifeline structure specially hospital building. The objective of this study is to evaluate seismic capacity and corresponding improvement of an existing hospital building (Ancillary Building) of Chittagong Medical College Hospital (CMCH). For this purpose, a three dimension (3-D) numerical model of Ancillary Building (AB) of CMCH was developed using SAP 2000 finite element program. A non-linear static analysis was performed to determine seismic capacity of the building model. The result indicates the seismic capacity of the hospital building is sufficient to mitigate the seismic demand according to BNBC-1993, whereas the seismic capacity is found insufficient as per revised BNBC. To reduce the seismic effect on AB, base-isolation devices have been designed and were used as link element to the numerical model. The application of base-isolation devices as a retrofitting strategy makes the considered hospital building safer for seismic excitation suggested in revised BNBC.

Keywords: *RCC hospital building, non-linear static analysis, seismic capacity and base-isolation.*

1.0 Introduction

Bangladesh is located in active seismic zone area, which has experienced at least 465 earthquakes of minor to moderate magnitude between 1971 and 2006 (Hasan and Bhuiyan, 2014). It indicates that this region has the highest possibility of occurring a strong earthquake in near the future (Hasan, 2015). The present construction practice is followed by the guideline provided in Bangladesh National Building Code (BNBC) which was developed in 1993 (BNBC, 1993). However most of the construction in Bangladesh before 1993 was done without any provision for seismic design. The recent study done by Comprehensive Disaster Management Programme (CDMP) indicates that this region might be stricken by a strong earthquake which will cause catastrophic damage in Bangladesh especially in Dhaka and Chittagong city. And CDMP research describes, the major losses will be due to not functioning of economically and socially important structure i.e. hospital, power station, etc. For this reason, the Bangladesh National Building Code-1993 (BNBC-1993) has been revised to consider greater effect of earthquake for designing structure (Hasan and Bhuiyan, 2015).

The BNBC-1993 suggests for consideration of 25% greater importance for hospital building than the standard occupancy building, whereas in Euro Code 8 (EC-8, 2004), Australian Building Code (AS11704, 1993) and New Zealand Building Code (NZS4203, 1992) suggest for providing 75%, 20% and 30% higher importance than normal building respectively. After all, it is observed that a number of hospital buildings were damaged due to earthquake around the world, which caused significant loss of life and economics. During the post-earthquake, the losses of life were found significantly higher since the injured peoples did not get proper treatment from hospitals as hospital were functionless. One of the examples is Northbridge Earthquake, in which more than twenty hospitals had to suspend some or all of their services (Huang and Li, 2008).

Bangladesh is country having only 678 hospitals which serves about 200 million people (Hasan, 2015). Among them only 27 hospitals are funded by government. Generally poorer peoples are taking treatment facilities from government hospital. Most of the hospitals were constructed prior to 1993 in which provision for seismic design did not follow properly. Among them Chittagong Medical College Hospital is the second largest hospital building in Bangladesh and largest in Chittagong City which is providing medical facilities to about 20 million people every year. The considered Ancillary Building of CMCH was constructed in 2001 by following the seismic design guideline provided in BNBC-1993. Hence, it is emphasized the need for investigation the seismic capacity of Ancillary Building to mitigate the earthquake force as per revised BNBC.

Retrofitting is the best suitable technology for seismic capacity improvement of existing vulnerable structures. There is various retrofitting strategy that can be implemented to a vulnerable building. Among them base-isolation is the most widely used innovative technology (Buckle and Mayes, 1990) which is used for the current study. Base-isolation not only provides safety against collapse, but also keeps hospital building functional during and after seismic event, which is crucial for hospital building.

2.0 Physical Description and Modelling of Existing Ancillary Building (AB)

The considered Ancillary Building of Cittagong Medical College Hospital is 10 story building with mat foundation. Figure 1 represents the AB of Chittagong Medical College Hospital (CMCH). Two types of column (rectangular and circular) were used in this building. The rectangular columns having six different physical dimensions are used here with maximum size of 750 mmX625 mm. Three types of circular column were used with maximum diameter of 625 mm. From structural drawings collected from

Public Works Department (PWD), Chittagong, Bangladesh, it is found that the compressive strength, modulus of elasticity and poisson ratio of concrete is 25 MPa, 23670 MPa and 0.2 respectively. The tensile strength and modulus of elasticity of steel is 415 MPa and 200000 MPa respectively. For modeling purposes the compressive strength and poisson ratio of clay brick are considered 13.7 MPa and 0.19 respectively. For structural analysis the hospital building need to make an analytical model which represent the actual condition of the building. For this, structural analysis software SAP 2000 has been used for modeling the hospital building. Beam and column elements are modelled as frame element; floor, roof, mat foundation and shear wall are modelled as shell element. The existence of masonry infill is modelled as equivalent strut model (Stafford, 1966). Figure 2 represents the analytical model of considered AB of CMCH.

Figure 1: Ancillary Building

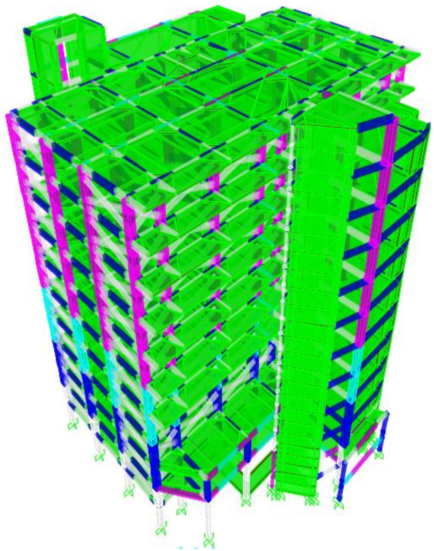

Figure 2: Analytical Model of AB

3.0 Pushover Analysis of Existing Ancillary Building

To evaluate the real strength of the existing AB non-linear static analysis is useful and effective tool. Force-deformation criteria for formation of hinges in beam and column are defined by ATC-40. As shown in Figure 3 (a) five points labelled A, B, C, D and E are used to define the force deflection behavior of the hinge and three points labelled IO, LS and CP are used to define the acceptance criteria for the hinge. IO, LS and CP indicate Immediate Occupancy, Life Safety and collapse prevention respectively. The values assigned to each of these points vary depending on the type of member as well as many other parameters defined in the ATC-40 and FEMA-356 documents. Figure 3 (b) and Figure 3 (c) represent characteristics of hinge of M3 and P-M3 respectively. M3 hinges are assigned in both end of every beam element whereas the P-M3 hinges are assigned in both end of every column.

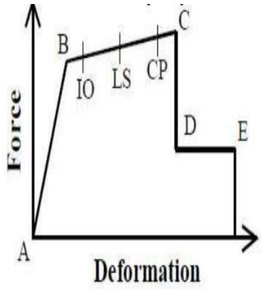

Figure3(a):Force-deformation relation for pushover hinges

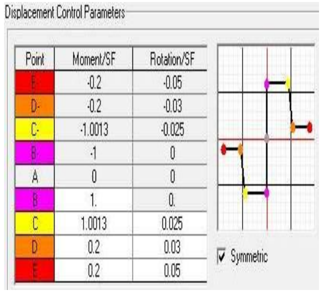

Figure 3(b): M3 hinge for beam element

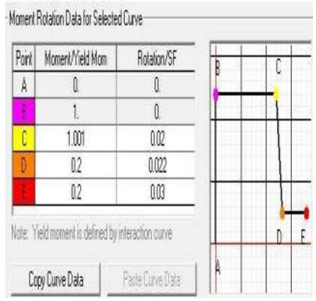

Figure 3(c): P-M3 hinge for column element

3.1 *Capacity and Capacity Spectrum Curve*

The pushover curve generally represents the value of the base shear and top displacement of the building. This curve is calculated using incremental static lateral loading on the structure. To determine the capacity of the existing building structure the existing hospitals 3D model is used which is explained past. After the application of dead load, the push over load is applied to the structure. Before staring analysis procedure the hinge property for vertical and horizontal structural elements are assigned as per FEMA-356 (FEMA-356, 2000).The displacements as loads are applied at any point in top floor of the structure. The characteristic of capacity curve is that it gives the information about strength of the structure. Figure 4 represents the pushover curve as a capacity curve of the existing hospital building (AB). The characteristic of the curve is, a part of it is straight and remaining portion is curve. The displacement Vs. base shear coordinates converted to spectral displacement (S_d) and spectral acceleration (S_a) respectively by use of modal participation factor ($PF_1\Phi_{R1}$) and effective modal participation weight ratios (α_1) as determined from dynamic characteristics of the fundamental mode of the structure (ATC-40, 1996). These values changes as the displacement shape changes. As equivalent inelastic period of vibration at various points along the capacity curve are calculated by use of Eq. 1

$$T_i = 2\pi\sqrt{S_{di}/S_{ai}} \qquad (1)$$

Now capacity spectrum curve can be plotted with the same coordinates as a response spectrum by following equations.

$$S_a = (\frac{V}{W}) \div \propto_1 \quad (2)$$

$$S_d = \frac{\Delta_R}{PF_1 \varphi_R} \pi r^2 \quad (3)$$

The capacity spectrum curve was obtained as shown in Figure 5. From the capacity spectrum curve it is clear that for spectral acceleration of 0.235g the yield point is observed which is marked as circle.

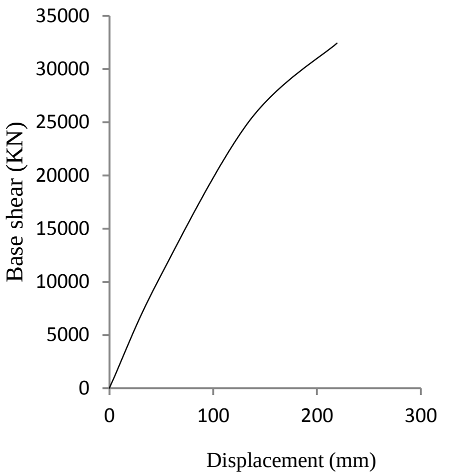

Figure 4: Base shear Vs Top Displacement

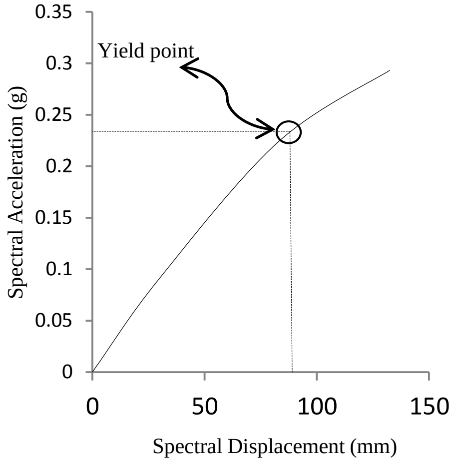

Figure 5: Capacity spectrum curve.

3.2 Bi-Linearization of Capacity Spectrum Curve

The capacity spectrum curve is bi-linearized for calculating the SR_A and SR_v value for computing inelastic response spectrum curve. For this reason the ATC-40 capacity spectrum method is followed here. Bi-linearization is done such way that the area under each envelope is same. Figure 6 represents the bi-linearization of capacity spectrum curve by adopting capacity spectrum method. The capacity spectrum curves are linearized and hysteresis loop are developed for computing the SR_A and SR_V values. The bi-linearized capacity spectrum curve is shown in Figure 7. For calculating effective viscous damping Eq. 4 is used and values for damping modification factor, K is given in Table 1. The effective viscous damping is calculated using following equation.

$$\beta_{eff} = k\beta_0 + 5 = \frac{63.7k(a_y d_{pi} - d_y a_{pi})}{a_{pi} d_{pi}} + 5 \quad (4)$$

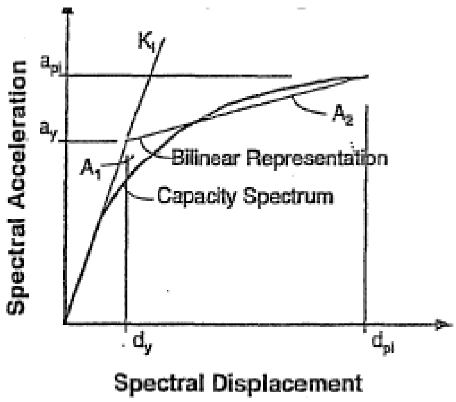

Figure 6: Bilinear representation of capacity spectrum for capacity spectrum method (ATC-40)

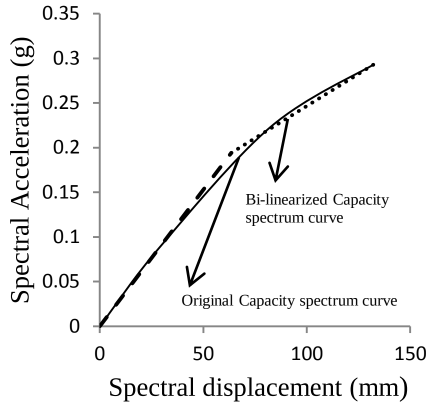

Figure 7: Bi-linearization of Capacity spectrum curve

Table 1: Values for damping modification factor, k (ATC-40)

Structural Behavior Type	β_0 *(Percent)*	*k*
Type A[2]	$\leq$ 16.25	1.0
	> 16.25	$1.13 - \frac{0.51(a_y d_{pi} - d_y a_{pi})}{a_{pi} d_{pi}}$
Type B	$\leq$ 25	0.67
	> 25	$0.845 - \frac{0.446(a_y d_{pi} - d_y a_{pi})}{a_{pi} d_{pi}}$
Type C	Any value	0.33

The equation for reduction factor for spectral acceleration and for spectral velocity is calculated using Eq. 5 and Eq. 6.

$$SR_A = \frac{3.21 - 0.681\ln(\beta_{eff})}{2.12} \quad (5)$$

$$SR_V = \frac{2.31 - 0.41\ln(\beta_{eff})}{1.65} \qquad (6)$$

The calculated value of SR_A and SR_V from Eq. 5 & Eq. 6 should not less than the value given in Table 2.

Table 2: Minimum allowable value of SR_A and SR_V (ATC-40)

Structural behavior type	SR_A	SR_V
Type A[2]	0.33	0.50
Type B	0.44	0.56
Type C	0.56	0.67

The spectral reduction factor is calculated. The reduction factors for vulnerable direction are found, SR_A =0.61156 and SR_V = 0.701805.

3.3 Performance Point and Performance Level

The elastic response spectrum (Demand curve) is converted to inelastic response spectrum curve. This is done by following the guideline provided by ATC-40. As per code, it is converted the 5% damped response spectrum curve to the demand spectrum. For this purposes the horizontal portion of damped response spectrum curve is multiplied by the response spectrum reduction factor SR_A and remaining portion is multiplied by the response spectrum reduction factor SR_V. Figure 8 represents capacity spectrum and 5% damped demand spectrum curve for corresponding PGA of 0.15g and PGA of 0.28g. The capacity spectrum curve intersects the 5% damped demand spectrum curve for PGA of 0.15g which indicates that the benchmark AB has sufficient earthquake resistant to mitigate the earthquake force for PGA of 0.15g. But it is also seen from the curve that the capacity curve did not intersect the 5% damped demand spectrum curve for corresponding PGA of 0.28g which indicates there is no performance point of the benchmark hospital building (existing AB). So due to earthquake load for PGA of 0.28g the benchmark Ancillary Building will not sustain and it will become functionless. The building performance level has been evaluated by FEMA-356 acceptance criteria as shown Table 3. In Push over analysis as shown in Table 3 hinges started forming in A-B stage and subsequently proceeding to B-IO and IO-LS stage. It is also observed that hinges are formed beyond collapse prevention level for a large displacement.

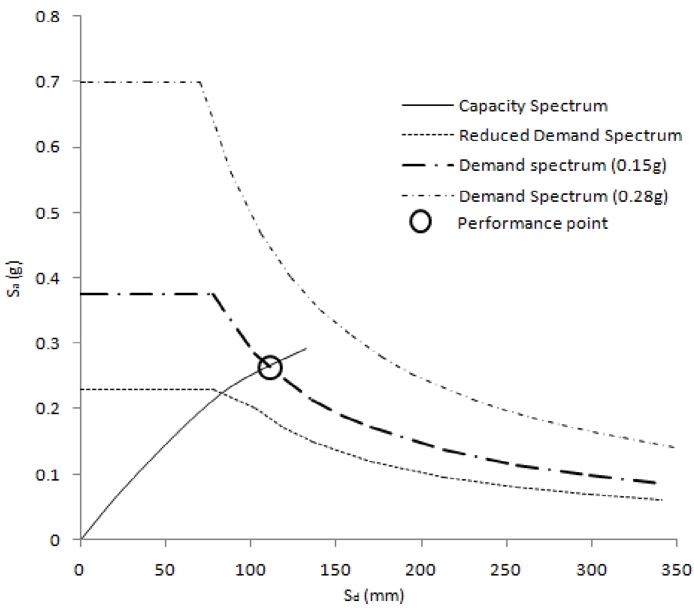

Figure 8: Performance point of benchmark hospital building (Ancillary Building)

Table 3: Formation of hinges in benchmark hospital building (Benchmark AB)

Step	Displacement (mm)	Base shear (KN)	A to B	B to IO	IO to LS	LS to CP	CP to C	C to D	D to E	Beyond E	Total
0	0	0	6550	0	0	0	0	0	0	0	6550
1	46.3	9970	6548	2	0	0	0	0	0	0	6550
2	134.6	25091	5976	574	0	0	0	0	0	0	6550
3	219.2	32428	5634	915	0	0	0	1	0	0	6550

At performance point, where the capacity meets demand, out of 6550 assigned hinges 5976 were in A-B stage and 574 stages were in B to IO for PGA 0.15g. The overall performance of building is said to be Immediate Occupancy (IO).

4.0 Retrofitting of Ancillary Building using Base-isolation Devices

It is observed from the performance point of the structure that the existing hospital building (Ancillary Building) will sustain for ground motion having PGA of 0.15g. But for earthquake having PGA of 0.28g the hospital building is not sufficiently earthquake resistant to carry the load. So it can be concluded that the existing hospital building is vulnerable for medium to strong earthquake and necessary retrofitting strategy need to be adopted to mitigate the earthquake disaster.

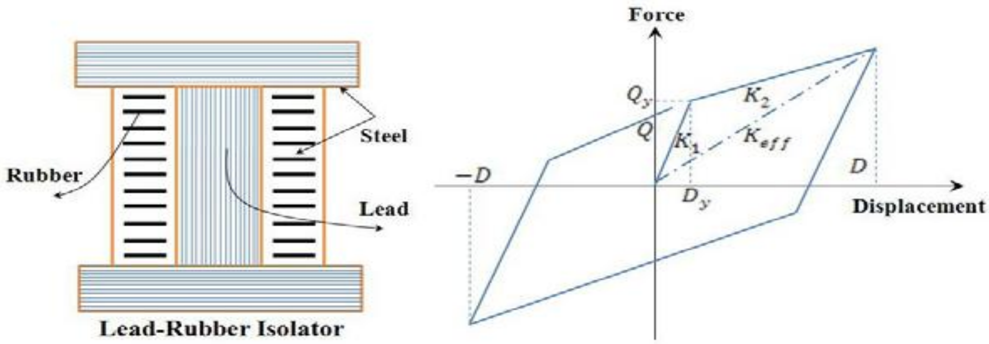

Figure 9: Lead Rubber isolator components with force displacement curve

Among the various available retrofitting methods, base-isolation (BI) devices is selected for retrofitting the considered hospital building because it will able to keep the hospital functional at all time even after major earthquake. Among the various types base-isolation devices the Lead Rubber Bearing (LRB) is effectively used for building retrofitting. The LRB consists of two steel plates at the top and bottom of the device, with several alternating steel shims and central lead core. Figure 9 represents the X-section of LRB devices with force displacement relationship. For designing of BI devices guideline provided by Japan Road Association, 2002 is followed. For design purposes shear strength of rubber is assumed as 6 MPa and maximum design displacement lies in between 100 to 400 mm. Standard value of shear strain of rubber is considered as 100% in USA and 200% in Japan (Kelly, 1997). In our case we assumed the value is 175%. Eq. 7, 8, 9, 10 & 11 has been used for computing properties of LRB.

$$k_1 = 6.5k_2 \tag{7}$$

$$k_2 = (F - q_d) / u_{(Be)} \tag{8}$$

$$q_d = q_0(\gamma_e)A_p \tag{9}$$

With,

$$q_0(\gamma_e) = b_0 + b_1\gamma_e \tag{10}$$

$$F = G_e A_e \gamma_e + A_p q_0(\gamma_e) \tag{11}$$

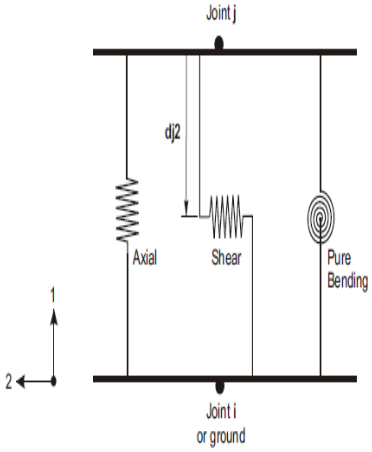

Figure 10: Three of the six independent springs in a Link/Support element

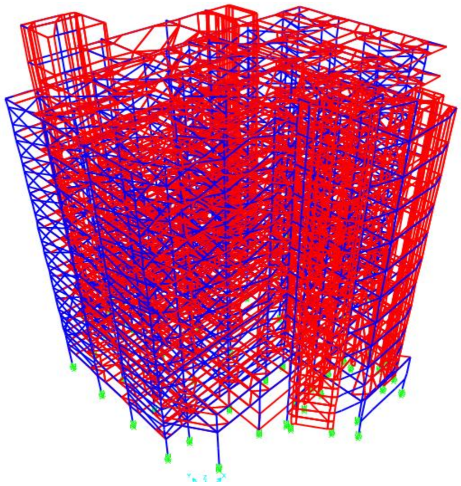

Figure 11: Analytical Model of base-isolated hospital building (base-isolated AB)

Using above equations and data, thirty one (31) BI devices have been designed having maximum size of 1300 mm*1300 mm and the smallest one is 250 mm*250mm. In SAP 2000, isolators are modeled using link/support element option. The shearing behavior is based on the model proposed by Park *et al*. (1986) and extended for seismic isolation bearings by Nagarajaiah *et al*. (1991). For the elastomeric bearing (rubber isolator) option in the link element, nonlinear (bilinear) properties are assigned to the two horizontal shear directions, but only linear elastic behavior is accommodated for the remaining axial and three rotational directions. Figures 10 and 11 represent the modelling of link element and analytical model of retrofitted Ancillary Building respectively.

5.0 Non-linear Static Analysis of Base-isolated Ancillary Building

After modelling base-isolated hospital building (base-isolated Ancillary Building), non-linear static analysis was carried out using SAP-2000. Firstly hinge properties are assigned for structural members. After that displacement at a reference point is assigned as a push over load in the structure.

5.1 Capacity Curve of Ancillary Building Before and After Retrofitting

The capacity of retrofitted hospital building (Retrofitted AB) is compared with benchmark AB which is shown in Figure 12. From Figure 12, it can be seen that the capacity of hospital building is increased due to application of base-isolation devices which is shown as base-isolated hospital building capacity curve. It is also seen from

Figure 12 that the global stiffness of retrofitted hospital is decreased due to presence of flexible rubber devices in bottom of structure.

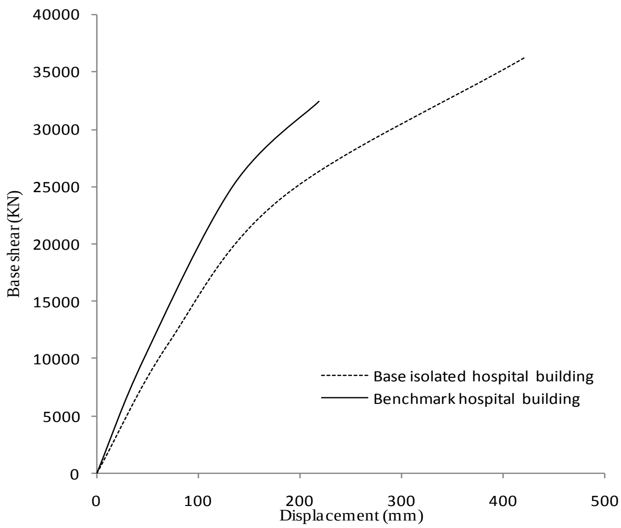

Figure 12: Capacity curve of Ancillary Building (before and after retrofitting)

5.2 *Performance Point and Performance Level of Base-Isolated AB*

Performance point can be obtained by super imposing capacity spectrum and demand spectrum and the intersection point of these two curves is performance point. When the demand curve intersects the capacity envelope near the elastic range, then the structure has a good resistance. If the demand curve intersects the capacity curve with little reserve of strength and deformation capacity, then it can be concluded that the structure will behave poorly during the imposed seismic excitation and need to be retrofitted to avoid future major damage or collapse. From Figure 13, it is clear that the capacity curve of base isolated Ancillary Building reaches up to the demand curve for earthquake magnitude having PGA of 0.28g. Two performance points have found for considered ground motions. So, it is concluded that the retrofitting approach makes the hospital building (Ancillary Building) safe for PGA of 0.15g and also for PGA of 0.28g. On the other hand it can say that by implementing BI isolation devices the hospital building (Ancillary Building) becomes safe for designed earthquake suggested in BNBC-1993 and revised BNBC. Table 4 represents the formation of hinges in base isolated Ancillary Building due to application of push over load. From following table it is seen that the formation of hinges lies in zone of B to IO. So the performance of base isolated Ancillary Building is Immediate Occupancy level.

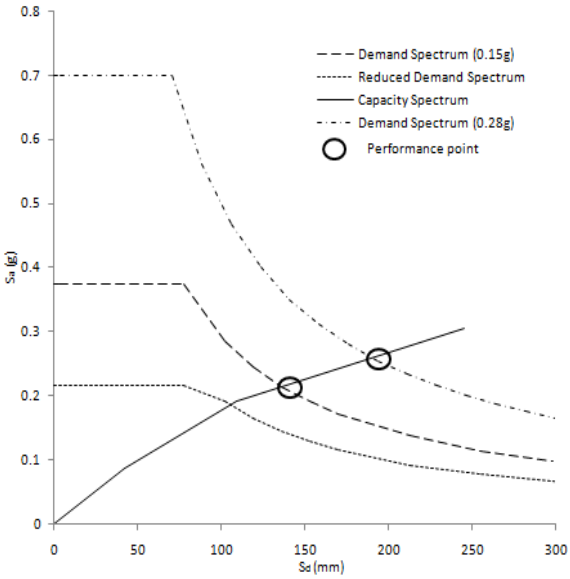

Figure 13: Performance point for base-isolated Ancillary Building

Table 4: Formation of hinges in base isolated hospital building (Base-isolated AB)

Step	Displacement (mm)	Base shear (KN)	A to B	B to IO	IO to LS	LS to CP	CP to C	C to D	D to E	Beyond E	Total
0	0	0	6594	0	0	0	0	0	0	0	6594
1	70.65	11315	6593	1	0	0	0	0	0	0	6594
2	183.2	24053	5894	700	0	0	0	0	0	0	6594
3	423.5	36297	5395	951	244	3	0	0	0	1	6594

6.0 Conclusions

From this study, it is found that the existing hospital building (Ancillary Building) has capacity to sustain for earthquake load having PGA of 0.15g which is suggested in BNBC-1993. But it has insufficient earthquake resistance capacity to mitigate the earthquake load of PGA 0.28g which is suggested in revised BNBC. If base-isolation devices as a proper retrofitting strategy is adopted then the capacity of the hospital building (Ancillary Building) is found to be increased which makes the building to able to withstand after earthquake of PGA 0.28g suggested in revised BNBC. So to avoid devastating situation the existing vulnerable Ancillary Building (AB) of Chittagong

Medical Hospital Building (CMCH) is needed to retrofit immediately using base isolation devices for keeping functioning all time even after major earthquake.

References

AS11704, (1993). Australian Building Code.

ATC-40, (1996). Seismic Evaluation and Retrofit of Concrete Buildings.

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

Buckle, I.G., and Mayes, R.L, (1990). Seismic Isolation: History, application and performance A world review, Earthquake Spectra, 6: 2: 161-201.

EC-8, (2004). Eurocode-8 Seismic Design Euro Code.

FEMA-356, (2000). Report on the Pre standard and commentary for the Seismic Rehabilitation of Buildings.

Hasan, M.A., (2015). *Assessment of Seismic Fragility and Retrofit of Hospital Building using Base-isolation Devices.* M.Sc Dissertation, Chittagong University of Engineering and Technology, Bangladesh.

Hasan, M. A., and Bhuiyan, R. A., (2014). *Seismic Performance Evaluation of Seismically Isolated Reinforced Concrete Building: A Case Study.*2nd International Conference on Advances in Civil Engineering (ICACE-2014) on 26-28 December, 2014, pp. 627-637, CUET, Bangladesh.

Hasan, M. A., and Bhuiyan, R. A., (2015). *Fragility Assessment of an Existing Reinforced* Concrete Hospital Building. 1st National Conference on Earthquake and Environmental Disaster on 17 December, 2015, pp. 26-32, CUET, Bangladesh.

Huang, H., and Li, W., (2008). *Research on development and distribution rules of geo-hazard induced by wenchan earthquake*, 12th Chinese Journal of rock mechanics and engineering 27(12):2585-2595.

Japan Road Association, (2002). *Specification for highway bridges - part V:Seismic design*, Tokyo, Japan.

Kelly, J.M., (1997). Earthquake Resistant Design with Rubber, 2nd Edition, Springer-Verlag Berlin Heidelberg, New York.

Nagarajaiah, S., Reinhorn, A.M., and Constantinou, M.C., (1991). *Nonlinear dynamic analysis of 3–D base isolated structures*, Journal of Structural Engineering, ASCE, Vol. 117, pp. 2035– 2054.

NZS 4203, (1992). New Zealand Building Code.

Park, Y.J., Wen, Y.K., and Ang, A.H.S.(1986). *Random vibration of hysteretic systems under bi-directional ground motions*, Earthquake Engineering and Structural Dynamics, Vol. 14, pp. 543-557.

Stafford, S.B., (1966). *Behavior of square In-Filled Frames*. Journal of the structural Division, ASCE, vol.92.