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ANALYSIS OF RCC BUILDING FOR MULTIPLE LEVELS OF SEISMIC ISOLATION

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Abstract— **A large proportion of world's population lives in regions of seismic hazards, at risk from earthquakes of varying severity and frequency of occurrence. Earthquake causes large number of loss of life and damage of property every year. So, to reduce the damage caused due to earthquake on building, seismic isolation is one of the best technical advantage used now a days. Seismic isolation is usually installed below the super structure. The main purpose of seismic isolation is to absorb energy transmitted to a building due to seismic activities, which reduces the damage cause to the superstructure. Middle storey isolation is a new technique of seismic isolation which was invented for strengthening of old weak structures to withstand seismic activities. This method was preferred over other strengthening methods due to cost effectiveness and efficiency of results.**

The purpose of this study is to find the performance of a 15 storey RCC building in terms of storey displacement, storey drift, storey acceleration, storey shear, base shear and time period when seismic isolators are installed at two different levels. Out of which one isolator would be base isolator and the other would be storey isolator; each storey would be isolated at once with base isolation. The most optimum position for using the storey isolator would be found out in this study.

Keywords— **Storey isolation, base isolation, response spectrum analysis, time period, storey displacement, storey acceleration**

I. INTRODUCTION

Seismic analysis of structure by linear dynamic or nonlinear procedures has been evolved in order to make the structure capable of resisting earthquakes. Earthquake analysis gives the seismic energies in terms of horizontal forces, accelerations etc., the building is then designed to resist these forces. Properly designed earthquake resistant buildings do not get structurally damaged during and after seismic activities but the equipment, installations in the building are prone to severe damage, also the people inside the building could get serious injuries, as shown in figure 1. However, seismic isolation is the concept where the building superstructure is isolated from the ground to insulate the seismic energies. Superstructure is partially separated from earthquake ground shaking which causes lesser input energies on the building leading to structural stability and safety of people and other property inside it as shown in figure 2. Base isolators provide overall flexibility at the base of the building which causes a decreased input acceleration and a period shift as shown in figure 4. Storey isolation is relatively a new concept which was developed and also practiced for strengthening of old structures to be stable in seismic activities. It was found out that middle-storey isolation technique meets the structural seismic requirements and service requirements of 'Immediate Occupancy' or continuing occupation at relatively lower cost than other strengthening methods. This concept and working is similar to the base isolation concept except the location of isolators. Storey isolation means isolating the particular storey level from lower storeys; the isolators are placed below the desired storey level. Middle-storey isolation and also the multiple levels of seismic isolation in a building is an immense area of study. Figure 3 shows isolation at three levels in a building. Seismic isolation at more than one level on the building can further improve the seismic performance and it can help further optimizing the structural design.

Fig. 1: Earthquake resistant building (https://www.kuraka.co.jp/en/technology)

Fig. 2: Base isolated building (https://www.kuraka.co.jp/en/technology)

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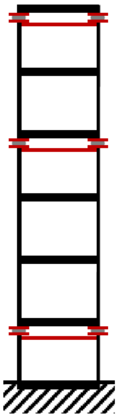

Fig. 3: Three seismic isolation levels (Phocas, 2012).

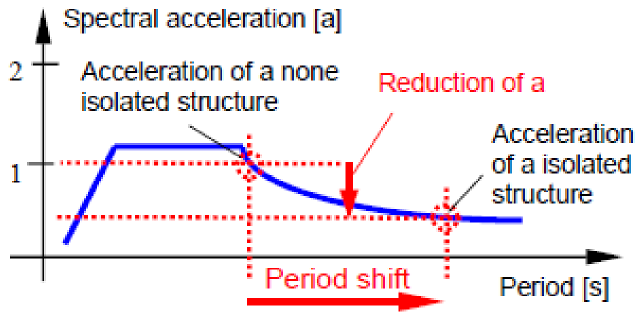

Fig. 4: Period shift due to base isolation (MAURER seismic isolation system with LRB, 2008)

Sahoo and Parhi (2018) conducted a study on base isolation of residential building using lead rubber bearing. By comparing analysis results of fixed and base isolated 10 storey and 15 storey buildings, they concluded that, base isolation increases time period, base displacement and the storey drift. Increase in time period lessens seismic forces on the structure. Cancellara and Angelis (2016) performed the seismic assessment of structure with two types of elastomeric isolators used with friction slider i.e. HDRB + FS and LRB + FS. They studied that LRB isolators show 15% to 30% greater dissipative capacity compared to HDRB. LRBs cause greater values of storey drifts. LRBs possess stable hysteretic cycles and negligible dependence on strain history. HDRBs show considerable dependence on strain history. Jangid and Matsagar (2008) investigated the construction practices for seismic retrofitting of structures using base isolation. They observed that base isolation reduces the seismic forces by a factor 0.3 to 0.8 in the superstructures, and controls the distribution of forces among substructures and foundations that enhances the economy and effectiveness of the retrofit designs. They suggested that the elastomeric and sliding bearings are effective in retrofitting of the buildings, bridges, and tank structures and the retrofitting work can be carried out without interrupting the regular activities.

Phocas et al. (2012) conducted parametric study on a 6 storey RCC structure with multiple storey isolation levels. All the combinations from the single base isolated structure to all storey isolated structure has been carried out. They concluded that, fundamental time period is increased as the number of isolators are increased, with slight decrease of displacement. The dynamic behavior of structure is substantially improved with respect to storey drifts, storey accelerations and the base shear force. They proposed that most optimum results are obtained when three levels are isolated at a time over the height. Xiangyun et al. (2008) did theoretical and experimental investigation on mid storey seismic isolation of 7 storey structure. They observed the performance by isolating each storey at once. They found out that first modal period of mid-storey isolated structure is more compared to fixed based structure; and in general first two modes are main control functions. Acceleration at isolation layer has sudden change as the stiffness of isolation layer is smaller. Deformation concentrates at the isolation layer. Storey displacement, except at isolation layer is smaller than corresponding fix based structure. Zhou et al. (2004[a]) had conducted a case study on the existing 9 storey RCC building isolated at an intermediate storey in Tokyo. They concluded that as compared with other strengthening methods such as K-shaped steel bracing, external cladding, energy absorbing vibration damping, base isolation; mid-storey isolation method meets the seismic requirements with ensuring concurrent occupation during retrofitting work with lesser cost. Zhou et al. (2004[b]) made a case study on the largest seismic isolated area in the world that includes a large 2 storey RCC platform supporting 50 numbers of 7-9 storey RCC buildings. The buildings were isolated from base platform. They concluded that the design horizontal seismic load for superstructure was decreased to 1/4th, cost saved about 25% and safety level increased 4 times and number of stories could rise from 6 to 9 over traditional anti-seismic structure.

The thorough analysis of previous literatures can be concluded with observation that the researchers have put stress on the concept of base isolation, properties of isolation bearings and middle storey isolation for strengthening purpose. A lot of work has been done in order to study behavior of isolation bearings and base isolated structures. It was found out that storey isolation is effective technique for strengthening of old buildings and it also can be used for new constructions. However the performance of a mid to high rise building, having fundamental natural time period greater than 1sec, by providing two isolation systems, one base isolation and one storey isolation at a time has not been evaluated so far. Similarly the optimized position of storey isolator used along with base isolator is not yet studied. The present study is based on finding out optimum location of story isolation along with base isolation for 15 storied RCC building.

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II. METHDOLOGY

A 15 storied RCC building having a grid plan as shown in figure 9 and 3D view as in figure 10, is analyzed using response spectrum method as per IS1893:2016, for 15 cases depending on the location of isolator, given in Table I. The proposed building is important building as specified in IS 1893:2016 with importance factor (I) as 1.5 and is proposed in seismic zone IV with zone factor (Z) as 0.24. Table II gives the general data for modelling of building and seismic data for seismic analysis of building as per IS 1893:2002. After basic modelling, LRB is inserted as spring and the properties are inserted as link property into ETABS. The input properties of LRB are as shown in Table III. For linear analysis effective stiffness, effective damping and vertical stiffness are required.

The building is modelled on ETABS with help of the input data. 15 such models are prepared with respective positions of isolators. After creation of models, loads are assigned. Dead load on all members, super dead load (wall load) and live load on slabs are assigned. All of these models are analyzed by response spectrum analysis after assigning link properties (isolator properties) as per the cases.

Response spectrum analysis is carried out for each 15 models as per IS 1893:2002, using response reduction factor as 5. Response spectrum load case in X- and Y- direction are applied to the structure (RSX and RSY) and then they are scaled with the help of base shear obtained by seismic coefficient method.

The live load assigned as per IS 875:2013 part II is 4kN/m2 and as per IS 1893:2002, the percentage of live load to be used for calculating seismic weight is 50% for live loads greater than 3kN/m2. Hence the mass source or the load combination used for calculation of seismic weight is (Dead load + super dead load+ 50% of live load).

The building with fixed base is modelled and analyzed as per response spectrum method of analysis and the results such as vertical loads and horizontal loads are used for selection of lead rubber isolator. The properties of isolator are taken from TENSA Industry's catalogue of seismic isolators. The isolator is selected based on the maximum vertical static load (NSLU), maximum vertical seismic load (NSEISM) and maximum design horizontal load (HBDB). The proposed building has NSLU = 5705kN, NSEISM = 1310.4kN and HBDB = 231.6kN. Based on these values TLRI-500-SM-175/105 isolator is selected from the catalogue. Table IV shows the properties of the selected isolator with limiting NSLU, NSEISM, HBDB values. Effective horizontal stiffness and effective damping values are required input of software for response spectrum analysis.

Table I: List of different positions of isolators proposed.

Sr.	Cases	Position of Isolators
1	Fixed	No isolators placed
2	BI	Base Isolation
3	BI+2	Base Isolated + 2nd Storey Isolated
4	BI+3	Base Isolated + 3rd Storey Isolated
5	BI+4	Base Isolated + 4th Storey Isolated
6	BI+5	Base Isolated + 5th Storey Isolated
7	BI+6	Base Isolated + 6th Storey Isolated
8	BI+7	Base Isolated + 7th Storey Isolated
9	BI+8	Base Isolated + 8th Storey Isolated
10	BI+9	Base Isolated + 9th Storey Isolated
11	BI+10	Base Isolated + 10th Storey Isolated
12	BI+11	Base Isolated + 11th Storey Isolated
13	BI+12	Base Isolated + 12th Storey Isolated
14	BI+13	Base Isolated + 13th Storey Isolated
15	BI+14	Base Isolated + 14th Storey Isolated

Table II: Modeling input data.

Building type	RCC
No. of bays in X direction	4 Bays @ 5 m c/c
No. of bays in Y direction	3 Bays @ 5 m c/c
No. of storey	15 Nos
Floor to floor height	3 m
Sizes of columns	500mm X 500 mm
Sizes of beams	230 mm X 500 mm
Thickness of slab	150 mm
Grade of concrete	M30
Grade of steel	Fe500
Seismic Zone	IV (Z = 0.24)
Soil Type	II (Medium Soil- Poorly graded sands or gravelly sands with little or no fines)
Importance Factor (I)	1.5
Response Reduction Factor (R)	5

Table III: Properties of LRB for modeling.

Effective Horizontal Stiffness	1000kN/m
Effective Damping	0.24%
Vertical Stiffness	1140000 kN/m

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Table IV: Properties of LRB (TENSA volume 07, product catalogue seismic isolators).

Rubber Diameter (D)	600 mm
Total Overall height (Htot)	337 mm
Total Rubber Thickness (Tq)	175 mm
Vertical Stiffness (Kv)	1140 kN/mm
Effective Horizontal Stiffness (Keff)	1 kN/mm
Effective Damping (Xeff)	24%
Horizontal Yielding Load (Fy)	131 kN
Horizontal Design Displacement (dbd)	292 mm
Horizontal Design Load (Hdbd)	285 kN
Maximum Vertical Static Load (NSLU)	655 kN
Maximum Vertical Seismic Load (NSEISM)	2650 kN

III. RESULTS AND DISCUSSION

A. Modal Time Period

The modal time periods for first two modes are as shown in Table V, for all the 15 models. First two modes are translational in Y direction and in X direction respectively. Fundamental modal period of the building increases from 2.5s to 4.2s when base isolation is applied; this indicates that frequency of vibration of the building is reduced due to base isolation. As storey isolation is applied along with base isolation, total displacement of the structure decreases with storey isolator moved from bottom to top storey, due to which time period of the building decreases.

B. Modal Participation Mass Ratio

Table VI shows the modal participation mass ratio for first two modes as obtained from analysis for all the 15 models (mode 1 is in Y direction and mode 2 is in X direction). In case of fixed base building the mass participation of first mode was 79.66%, after base isolation mass participation of first mode became 95.93%. When storey isolation is applied with base isolation the increase in mass participation is seen up to 12th storey isolation and the slight decrease is there. For BI+12 case the maximum value of 99.39% is observed for first mode.

C. Storey Displacement

The top storey displacement of fixed base building is 123.6mm for response spectrum load case in X direction (RSX load case). All other building models have base isolation due to which first storey is displaced drastically from its position and then increase in displacement with height is lesser as compared to fixed base model as seen in figure 5. The model which is isolated below ground as well as below 12th storey (case BI+12) gives least increase in displacement observed from ground to top storey amongst all other cases. The difference in maximum and minimum displacement for fixed base is 117mm and for BI+12 case is 20mm leads to the stability of the building.

D. Storey Drift

The storey drift values for RSX load case for all the models are represented graphically in figure 6. The drift values for 1st storey are maximum because base isolator displaces the ground level drastically from its position. These values are not shown in graphs for simplification. From figure, it can be seen that case BI+12 gives the least drift values amongst all other cases because it has very little increase in displacement with height. Also, BI+12 case gives the minimum value of minimum drift.

E. Storey Acceleration

In case of RSX load case, the top storey acceleration of fixed base building is 1427mm/sec^2 while that of for base isolated building it is much lesser, 521.7mm/sec^2. Base isolated building has least acceleration values amongst all cases and has 25% difference in its maximum and minimum acceleration values. Amongst the cases of base isolation with storey isolation, BI+12 case shows comparatively stable values of storey acceleration throughout the height, as shown in figure 7. Also the difference between maximum and minimum values of acceleration for BI+12 is 15% which is lesser than that of base isolated building (BI).

F. Storey Shear

Figure 8 shows the graphical representation of the storey shear values for RSX load case. Base shear for fixed base building is 3404kN while that of for base isolated building is decreased to 2353kN. The sudden change in shear value is due to flexibility induced by the isolator. Minimum base shear of 1351kN is observed with BI+2 case and minimum storey shear of 81kN is observed with BI+13 case. In BI+12 case, at any storey level, shear doesn't exceed base shear value unlike all other cases, and also the variation in storey shear is lesser compared to other cases, with some exception.

G. Comparison of Results

The storey displacement obtained for present study and as obtained by Sahoo (2018) is compared in figure 9. The displacement pattern for fixed base building and base isolated building is similar but values obtained in present study are greater. This difference in values of displacement is due to the difference in sizes of beams and columns, difference in seismic zone and the properties of LRB used. The sizes of beams and columns provided by Sahoo (2018) are large enough to provide rigidity to the building, also they have considered seismic zone III and importance factor as 1; hence their fixed base building displaces only by 49mm at roof level.

Whereas in present study, sizes of beams and columns are comparatively smaller, seismic zone considered is IV and importance factor as 1.5. This causes building to displace by more amounts. From figure 10, it can be observed that drift values for present study are quite higher than that obtained by Sahoo (2018). This is mainly because of lesser sizes of beams and columns in present study that makes the structure comparatively flexible. Importance factor and seismic zone also responsible for more drift. Sahoo (2018) have used lead rubber isolator with higher stiffness than present study hence the base displacement in their study is comparatively lesser and drift values are same as fixed base building, unlike in present study where drift values of base isolated building are lesser than that of fixed base building.

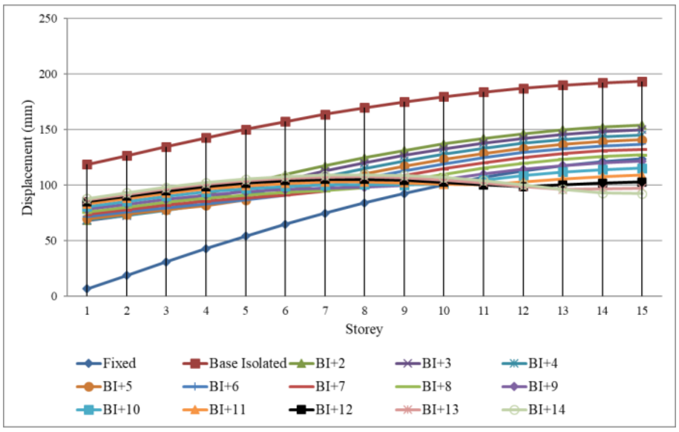

Fig. 5: Storey displacement for RSX load case.

Table V: Modal time period.

Cases	Time Period (sec)	
	Mode 1	Mode 2
Fixed	2.569	2.494
BI	4.248	4.205
BI+2	3.333	3.288
BI+3	3.219	3.181
BI+4	3.109	3.077
BI+5	3.003	2.978
BI+6	2.907	2.886
BI+7	2.821	2.805
BI+8	2.748	2.737
BI+9	2.692	2.684
BI+10	2.653	2.647
BI+11	2.632	2.627
BI+12	2.628	2.624
BI+13	2.641	2.636
BI+14	2.667	2.661

Table VI: Modal participation mass ratio.

Cases	Modal Mass Participation Ratio (%)	
	Mode 1 Y axis	Mode 2 X axis
Fixed	0.7966	0.8004
BI	0.9764	0.9790
BI+2	0.9403	0.9450
BI+3	0.9387	0.9435
BI+4	0.9398	0.9446
BI+5	0.9439	0.9485
BI+6	0.9511	0.9552
BI+7	0.9606	0.964
BI+8	0.9714	0.9739
BI+9	0.9818	0.9834
BI+10	0.9900	0.9908
BI+11	0.9949	0.9953
BI+12	0.9967	0.9969
BI+13	0.9963	0.9966
BI+14	0.9950	0.9954

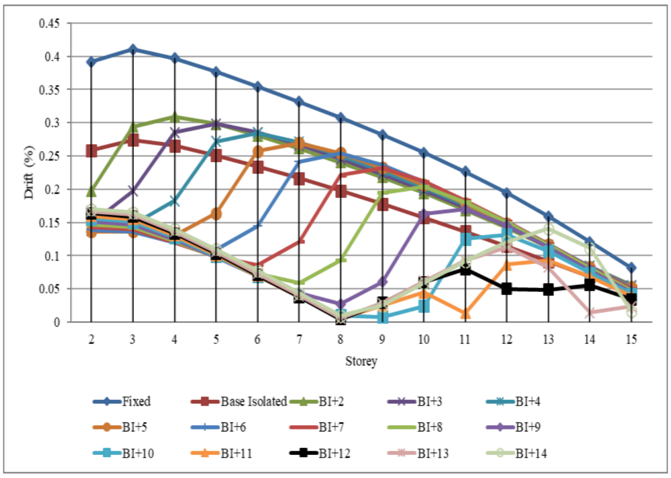

Fig. 6: Storey drift for RSX load case.

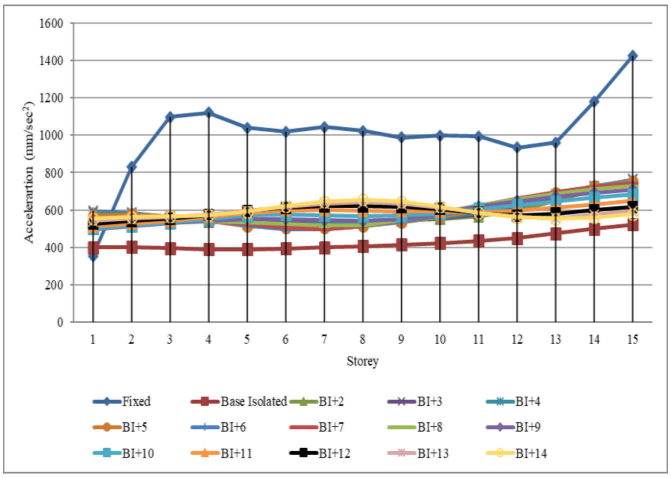

Fig. 7: Storey acceleration for RSX load case.

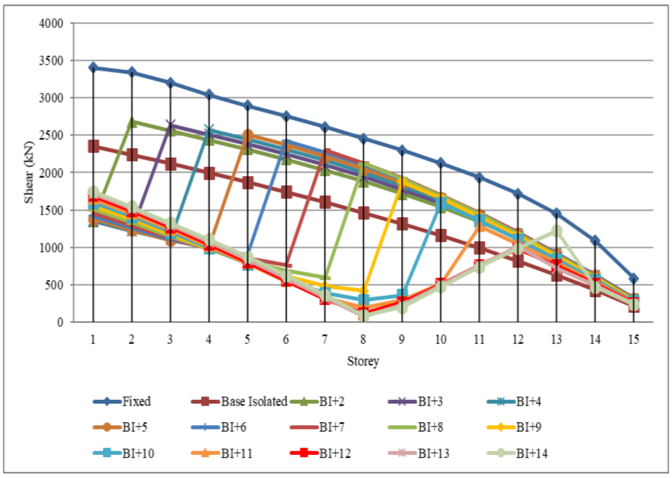

Fig. 8: Storey shear for RSX load case.

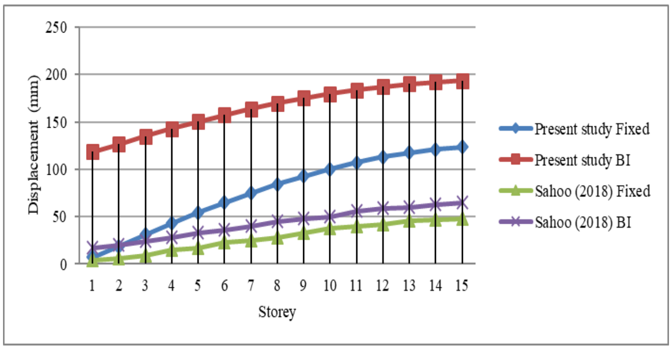

Fig. 9: Comparison of storey displacement.

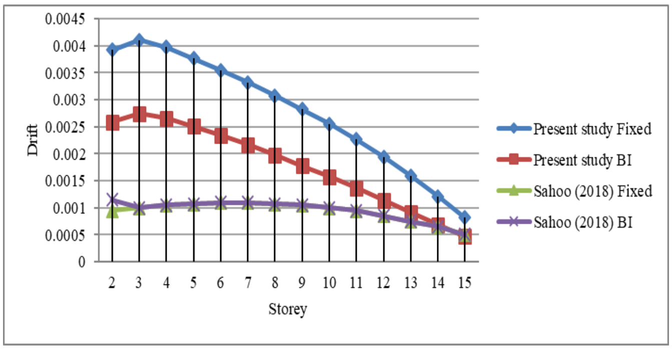

Fig. 10: Comparison of storey drift.

IV. CONCLUSIONS

Bases on the results obtained in the present study, following conclusions are drawn.

1. Base isolation technique is effective in improving overall seismic performance of the building. Base isolation along with the storey isolation further improves the performance.
2. Fundamental modal period of building without base isolation was 2.56sec which was increased to 4.24sec with the use of base isolator; and further use of storey isolation with base isolation reduced the time period, up to 2.66sec for BI+14 case.
3. Modal participation ratio of first mode increased from 79.6% to 97.6% by using base isolation and with storey isolation the maximum increase is 99.67% for BI+12 case.
4. BI+12 case gives the most stable values of storey displacement throughout the height of building. The difference in maximum and minimum displacement for fixed base building is 117mm while that for BI+12 case is 20mm.
5. The maximum storey drift is reduced by 60% with the use of base isolation along with 12th storey isolation (BI+12 case), as compared with fixed base building.
6. Storey accelerations were small and almost constant (25% difference in maximum and minimum value) throughout the height of building when base isolation was used, as compared to fixed base building where accelerations are changing by considerable amount over the height. Also with BI+12 case storey acceleration values were constant with only 15% difference in maximum and minimum values.
7. Base shear was reduced by 30% with base isolation and by 50% with BI+12 case. Minimum base shear was with BI+2 case and minimum storey shear was observed with BI+13 case. With BI+12 case, variation observed in storey shear was comparatively lesser than other cases, also the storey shear did not exceed base shear value.
8. With the study of all the results, it is concluded that the most optimum location of storey isolator to be used in combination with base isolator is the 12^{th} storey or 4/5th of the total height of building.

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