Parametric Study of 3 and 6 Storey Base Isolated building with Superstructure Eccentricity

Jay Assudani[1], Prof. S. P. Thakkar[2]
[1]Structrual Engineer , DuCone Consultant.
[2]Asst. Professor, Civil Engineering Department, Institute of Technology, Nirma University.

Abstract—***A parametric study of three and six storey base isolated building with mass and stiffness eccentricity is presented in this paper. Non linear Response Spectrum Analysis was carried out for Kobe(1995) ground motion. Lead Rubber bearing was used as base isolation system. The behavior of three and six storey building with mass eccentricity and stiffness eccentricity was compared with fixed building. Various parameters like Base shear, time period, displacement and storey drift were compared and it was concluded that eccentricity due to position of mass plays a more important role than that related to stiffness in governing the torsional behavior of structure***.

Key words: Base isolated structure, Mass eccentricity, Stiffness eccentricity

I. INTRODUCTION

All the engineering structures are build to satisfy the condition that capacity of the structure should always be greater than demand on the structure. Vibration control of civil structures is more recent as compared to machines and aerospace vehicles. Earthquakes and wind loads are main sources of structural vibrations which can be controlled by changing rigidity, mass, stiffness, damping, shape or applying passive or active control forces. Conventional design adopts the principle of either increasing the capacity of the structure or limiting the demand by considering the ductility of the structure. This results into either enlargement of the structural member sizes to increase the capacity or providing convention seismic design approach like shear walls, moment frames or braced frames which will increase the resistance of the building against the lateral forces. But this results into the large floor accelerations in stiff buildings and large inter storey drifts in flexible buildings. Hence, special techniques are required to design buildings such that they remain practically undamaged even in a severe earthquake. One basic technology used now a day to protect buildings from earthquake effects is the base isolation technology.

II. PRINCIPLE OF BASE ISOLATION

The concept behind base isolation is to decouple the building from the ground in such a way that the earthquake motions are not transmitted up through the building, or are at least greatly reduced. The principle of seismic isolation is to introduce flexibility at the base of a structure in the horizontal plane, while at the same time introducing damping elements to restrict the amplitude of the motion caused by the earthquake. Mounting buildings on an isolation system will prevent most of the horizontal movement of the ground from being transmitted to the buildings. These results in a significant reduction in floor accelerations and inter story drifts. Since a base-isolated structure has fundamental frequency lower than both its fixed base frequency and the dominant frequencies of ground motion, the first mode of vibration of isolated structure involves deformation only in the isolation system whereas superstructure remains almost rigid. In this way, the isolation becomes an attractive approach where protection of expensive sensitive equipments and internal non-structural components is needed[1],[2].

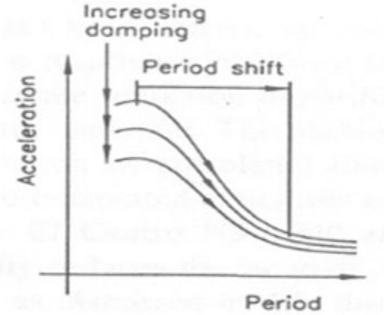


Fig. 1 Time period shift effect by seismic base isolators

II. TYPES OF BASE ISOLATORS

The most common type of base isolators used in buildings are:

1. Laminated Rubber (Electromeric) Bearing.
2. High Damping Rubber Bearing
3. Flat Slider Bearing
4. Lead Rubber Bearing
5. Friction Pendulum System.

Electromeric bearings / Laminated Rubber Bearing System: have been used widely in bridges as bearings pads between the girder and the supporting structure for many years. It consists of electromeric bearings have multiple layers of steel shims and rubber laminated together under high pressure and heat in a mould. Steel shims prevent lateral bulging of the rubber when axial loaded as they do not resist shear forces and do not prevent the horizontal deformation of the layered rubbers. Steel shims increase the vertical stiffness of isolator but do not increase the lateral stiffness of electrometric bearings. Generally, electromeric bearings have low critical damping resistance, approximately 2% to 3% of critical viscous damping and have minimum resistance under service loads.

High Damping Rubber Bearings: are similar in shape to the electrometric bearing, except that it is made of specially compounded rubber layers that are usually made of materials that are highly nonlinear in terms of shear strains. In HDR, the effective damping is a function of strain and effective stiffness and damping depend on electrometric properties, fillers, contact pressure, velocity of loading, load history, temperature.

Flat Slider Bearings: This bearings provide hysteresis shape with no strain hardening after the applied force exceeds the coefficient of friction times the applied vertical load. This is attractive from a structural design perspective as the total base shear on the structure is limited to the sliding force. In this system displacements are unconstrained and structure continues to move in the same direction.

Lead Rubber Bearings: The lead rubber bearing is formed of a lead plug force-fitted into a pre-formed hole in an electrometric bearing. The lead core provides rigidity under service loads and energy dissipation under high lateral loads. Top and bottom steel plates, thicker than the internal shims, are used to accommodate mounting hardware. The entire bearing is encased in cover rubber to provide environmental protection, as shown in Fig. 2.When subjected to low lateral loads such as earthquake & wind, the lead rubber bearing is stiff both laterally and vertically. The lateral stiffness results from the high elastic stiffness of the lead plug and the vertical rigidity results from the steel-rubber construction of the bearing. At higher load levels the lead yields and the lateral stiffness of the bearing is significantly reduced. This produces the period shift effect characteristic of base isolation. As the bearing is cycled at large displacements such as during moderate and large earthquakes, the plastic deformation of the lead absorbs energy as hysteretic damping. The equivalent viscous damping produced by this hysteresis is a function of displacement and usually ranges from 15% to 35% [3].

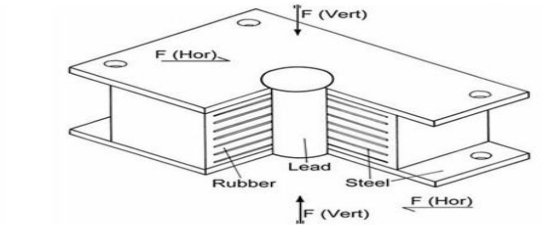


Fig. 2 Lead Rubber Bearing

Friction Pendulum System: This approach for increasing flexibility in a structure is by providing a sliding or friction surface between the foundation and the base of the structure. The isolator provides a resistance to service load by the coefficient of friction, as for flat slider. Once the coefficient of friction is overcome the articulated slider moves and because of the accompanied with a vertical movement of the mass provides a restoring force.

III MODELLING OF 3 AND 6 STOREY BUILDING WITH SUPER STRUCTURE ECCENTRICITY

Though it is a well known fact that earthquake resistance is maximum in regular and symmetric building, buildings with asymmetry in plan and elevation are most often preferred by both architects and investors due to the superior outlook. Hence, an attempt was made to study the effect of mass and stiffness eccentricity in base isolated building for 3 and 6 storied building. Lead rubber bearing was used as isolators. These results were compared with fixed building of same plan area. There were total nine models created which included one fixed base building and four base isolated buildings with 0 %, 5%, 10% and 15% of mass and stiffness eccentricities in the super structure [4]. In order to study the effect of static eccentricity, there was uniform distribution of lead rubber isolators and also no eccentricity in any floor i.e. e =0 was done. SAP 2000 software was used for modeling and analysis of the building.

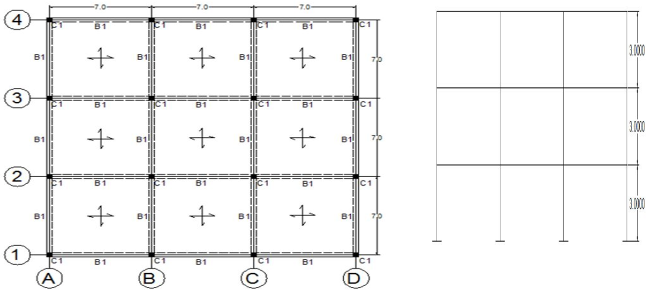


Fig. 3 Plan and Elevation of 3 storied building

For the parametric study concrete of grade M 25 and steel grade of Fe 415 was used. Loading consisted of self weight of slab 3 kN/m^2, floor finish of 1 kN/m^2 and Live load of 3kN/m^2. Mass eccentricity was achieved by changing hatched portion of slab thickness as shown in Fig. 4 to shift the centre of mass on one side of building.

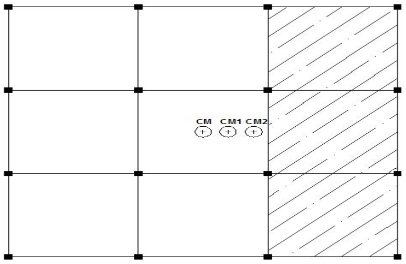


Fig.4 Panel with different thickness to shift centre of mass

Table 1 indicates the element sizes to be used to achieve different eccentricities

TABLE 1
Approximate member size for mass eccentricities

Sr. No.	Element	Size (mm)
1	Beam	350 × 750
2	Column	500 × 500
3	Slab for Fixed Base Building	120
4	Slab Thickness for Base Isolated Building with 0% Eccentricity	120
5	Slab Thickness for Base Isolated Building with 5% Eccentricity	185
6	Slab Thickness for Base Isolated Building with 10% Eccentricity	240
7	Slab Thickness for Base Isolated Building with 15% Eccentricity	320

Similarly variation of column sizes was done for achieving stiffness eccentricities and to shift the centre of stiffness.

TABLE 2
Approximate member size for stiffness eccentricities

Sr. No.	Element	Size (mm)
1	Beam	350 × 750
2	Column	500 × 500
3	Column Sizes for Base Isolated Building with 5% Eccentricity	530 × 530
4	Column Sizes for Base Isolated Building with 10% Eccentricity	565 × 565
5	Column Sizes for Base Isolated Building with 15% Eccentricity	610 × 610

IV PROPERTIES AND LOCATION OF LEAD RUBBER ISOLATORS

Base isolators were provided at the base of all the columns and had both vertical and horizontal stiffness. The yield strength of the isolators was taken as 5% weight of the structure and post to yield stiffness ratio was taken as 0.1[1]. The properties of isolators used in calculation of parameter are defined in Table 3 and Kobe earthquake(1995) was used for Response Spectrum Method with earthquake applied in X direction. Target design time period of 2.5 s was considered in the design of lead rubber bearing.

TABLE 3
Properties of Isolators

Sr. No.	Name of Property	Values
1	Vertical stiffness of isolator	462617.65 kN/m
2	Horizontal stiffness of isolator	4136.65 kN/m
3	Effective damping of isolator	10%
4	Yield strength of isolator	643.10 kN
5	Post to yield stiffness ratio	0.10

V COMPARISON OF THREE AND SIX STOREY BASE ISOLATED BUILDING WITH ECCENTRICITY

Non linear response spectrum analysis of base isolated building with mass and stiffness eccentricities was carried out and parameters like time period, base shear, storey drift and displacement were used to evaluate the response of these building compared with fixed building[5],[6],[7].

Three storey base isolated building

Time Period: Graphical comparison of Mode v/s Time period of base isolated building with 5%, 10% and 15% of mass and stiffness eccentricities was done as shown in Fig.5 and it was found that base isolated building with mass eccentricity has more time period compared to stiffness eccentricity. The time period for the base isolated buildings with 5%, 10%, and 15% of mass eccentricities was increased by 1.045, 1.089 and 1.155 times respectively, compared to the stiffness eccentricities in the building.

Fig. 5 Comparison of Time Period for Mass and Stiffness eccentricities

Base Shear: The graphical representation of comparison of base shear for base isolated buildings of 5%, 10% and 15% of mass eccentricities and stiffness eccentricities is shown in Fig. 6

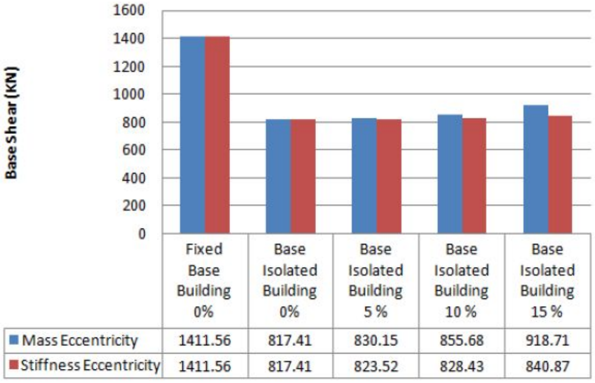
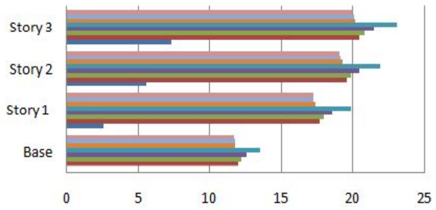


Fig. 6 Comparison of Base Shear for Mass and Stiffness eccentricities

The base shear for the base isolated buildings with 5% , 10%, and 15% of mass eccentricities is increased by 1.00%, 3.18% and 8.47% respectively, compared to the stiffness eccentricities in the building, making it evident that building with mass eccentricity has more base shear compared to stiffness eccentricity.

Displacement:

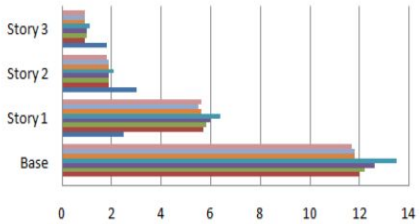


	Base	Story 1	Story 2	Story 3
■ 15% Stiffness Eccentricity	11.7	17.3	19.1	20.0
■ 10% Stiffness Eccentricity	11.8	17.3	19.2	20.1
■ 5% Stiffness Eccentricity	11.8	17.4	19.3	20.2
■ 15% Mass Eccentricity	13.5	19.9	22.0	23.1
■ 10% Mass Eccentricity	12.6	18.6	20.5	21.5
■ 5% Mass Eccentricity	12.2	18.0	19.9	20.9
■ Base isolated building	12.0	17.7	19.6	20.5
■ Fixed base building	0	2.50	5.50	7.30

Fig. 7 Comparison of Displacement for Mass and Stiffness eccentricities

Fig. 7 shows the graphical representation of comparison of different percentage mass and stiffness eccentricities. It can be inferred that displacement is increased by 3.35 % to 13.41% of mass eccentric base isolated structure compared to stiffness eccentric base isolated structure.

Storey Drift: the storey drift at the top of the building of base isolated buildings with 5% and 10% of mass eccentricities is increased by 10.00% and for 15% of mass eccentricity are increased by 18.18%, compared to the stiffness eccentricities in the building as shown in Fig. 8**.** Thus, indicating that the base isolated buildings with mass eccentricity have more displacement compare to the stiffness eccentricity.

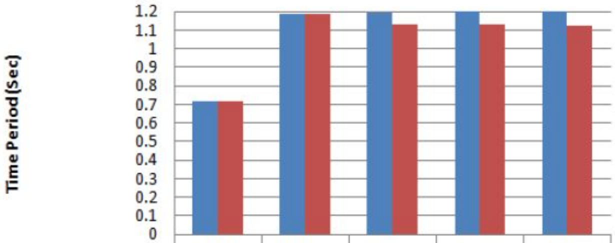


	Base	Story 1	Story 2	Story 3
■ 15% Stiffness Eccentricity	11.7	5.6	1.8	0.9
■ 10% Stiffness Eccentricity	11.8	5.5	1.9	0.9
■ 5% Stiffness Eccentricity	11.8	5.6	1.9	0.9
■ 15% Mass Eccentricity	13.5	6.4	2.1	1.1
■ 10% Mass Eccenricity	12.6	6.0	1.9	1.0
■ 5% Mass Eccentricity	12.2	5.8	1.9	1.0
■ Base isolated building	12	5.7	1.9	0.9
■ Fixed base building	0	2.5	3	1.8

Fig. 8 Comparison of Storey Drift for Mass and Stiffness eccentricities

Six storey Base Isolated building

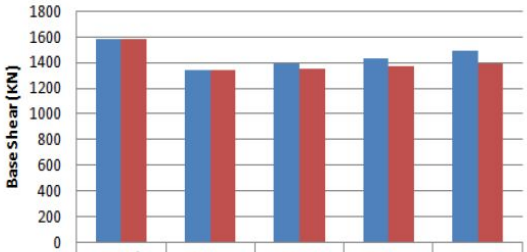
Time Period: The graphical representation of comparison of Mode vs time period for base isolated 6 storey buildings of 5%, 10% and 15% of mass eccentricities and stiffness eccentricities is shown in Fig. 9. From results, it is evident that the base isolated buildings with mass eccentricity have more time period compare to the stiffness eccentricity , which increases from 1.053 times to 1.175 times with different eccentricity for first mode.



	Fixed Base Building 0%	Base Isolated Building 0%	Base Isolated Building 5 %	Base Isolated Building 10 %	Base Isolated Building 15 %
■ Mass Eccentricity	0.7167	1.1898	1.1932	1.2439	1.3199
■ Stiffness Eccentricity	0.7167	1.1898	1.1333	1.1278	1.1228

Fig. 9 Comparison of Time Period for Mass and Stiffness eccentricities

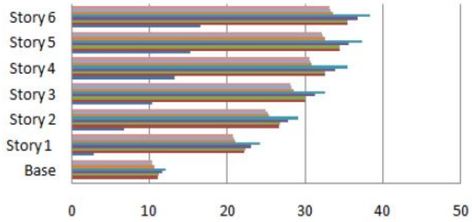
Base Shear : The base shear for the base isolated buildings with 5%, 10%, and 15% of mass eccentricities is increased by 2.58%, 4.70% and 8.14% respectively, compared to the stiffness eccentricities in the building (Fig.10).



	Fixed Base Building 0%	Base Isolated Building 0%	Base Isolated Building 5 %	Base Isolated Building 10 %	Base Isolated Building 15 %
■ Mass Eccentricity	1586.13	1340.41	1388.31	1436.21	1490.24
■ Stiffness Eccentricity	1586.13	1340.41	1352.44	1368.74	1386.89

Fig. 10 Comparison of Base Shear for Mass and Stiffness eccentricities

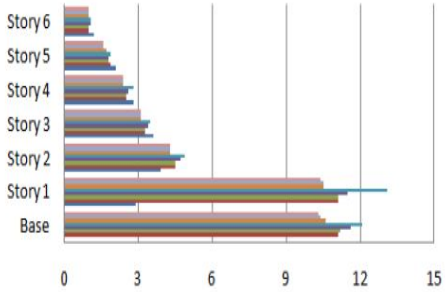
Displacement: The displacement of the base isolated buildings with 5%, 10% and 15% of mass eccentricities is increased by 5.08%, 9.26% and 13.80% respectively, compared to the stiffness eccentricities in the building as represented in Fig. 11



	Base	Story 1	Story 2	Story 3	Story 4	Story 5	Story 6
■ 15% Stiffness Eccentricity	10.3	20.7	25	28.1	30.5	32.1	33.1
■ 10% Stiffness Eccentricity	10.4	20.9	25.2	28.3	30.7	32.3	33.3
■ 5% Stiffness Eccentricity	10.6	21.1	25.4	28.5	30.9	32.6	33.6
■ 15% Mass Eccentricity	12.1	24.2	29.1	32.6	35.4	37.3	38.4
■ 10% Mass Eccentricity	11.6	23.1	27.8	31.2	33.8	35.6	36.7
■ 5% Mass Eccentricity	11.2	22.3	26.8	30.1	32.6	34.4	35.4
■ Base isolated building	11.1	22.2	26.7	30.0	32.5	34.4	35.4
■ Fixed base building	0	2.90	6.80	10.4	13.2	15.3	16.5

Fig. 11 Comparison of Displacement for Mass and Stiffness eccentricities

Storey Drift: Fig.12 shows the graphical representation of comparison of storey drift for base isolated buildings of 5%, 10% and 15% of mass eccentricities with stiffness eccentricities. From results, it is evident that the base isolated buildings with mass eccentricity have more displacement compare to the stiffness eccentricity.



	Base	Story 1	Story 2	Story 3	Story 4	Story 5	Story 6
■ 15% Stiffness Eccentricity	10.3	10.4	4.3	3.1	2.4	1.6	1.0
■ 10% Stiffness Eccentricity	10.4	10.5	4.3	3.1	2.4	1.6	1.0
■ 5% Stiffness Eccentricity	10.6	10.5	4.3	3.1	2.4	1.7	1.0
■ 15% Mass Eccentricity	12.1	13.1	4.9	3.5	2.8	1.9	1.1
■ 10% Mass Eccenricity	11.6	11.5	4.7	3.4	2.6	1.8	1.1
■ 5% Mass Eccentricity	11.2	11.1	4.5	3.3	2.5	1.8	1.0
■ Base isolated building	11.1	11.1	4.5	3.3	2.5	1.9	1.0
■ Fixed base building	0	2.9	3.9	3.6	2.8	2.1	1.2

Fig. 12 Comparison of Storey Drift for Mass and Stiffness eccentricities

VI DISCUSSIONS

- The time period for the base isolated buildings with 5%, 10%, and 15% of mass eccentricities was increased by 1.045, 1.089 and 1.155 times respectively, compared to the stiffness eccentricities in the building of three storey, while for six storey building the increase is 1.053,1.103 and 1.175 times respectively for the same eccentricity for the first mode of vibration.
- The base shear for the base isolated buildings with 5%, 10%, and 15% of mass eccentricities was increased by 1.00%, 3.18% and 8.47% respectively, compared to the stiffness eccentricities in the building of three storey. In case of six storey building with same percentage of mass eccentricities the increase was by 2.58%, 4.70% and 8.14% respectively, compared to the stiffness eccentricities in the building.
- The displacement for the base isolated three storey building with 5%, 10% and 15% of mass eccentricities was increased by 3.35%, 6.51% and 13.41% respectively, and for six storey building it's increased by 5.08%, 9.26% and 13.80% compared to the stiffness eccentricity of same percentage.
- The storey drift of the three storey base isolated buildings with 5% and 10% of mass eccentricities are increased by 10.0% and for 15% of mass eccentricity are increased by 18.18%, compared to the stiffness eccentricities, while in the building of six storey the increase was by 9.09% for 10% and 15% of mass eccentricities compared with stiffness eccentricity

VII CONCLUSION

Thus from the above study it can be concluded that for same percentage of eccentricity between mass and stiffness time period increase with number of storey but there is increase in displacement also. While the base shear reduction is reduces to small amount with number of storey indicating that base isolated structure are good for limited storey only. It can also be concluded from the above results that a higher base shear and storey drift exits in base isolated buildings with mass eccentricities in the superstructure than the base isolated buildings with stiffness eccentricities in the superstructure for 3 and 6 storey buildings.

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