Study of seismic response of symmetric and asymmetric base isolated building with mass asymmetry in plan
Khante.S.N¹, Lavkesh R.Wankhade²

¹- Associate Professor, Applied Mechanics Department, Government College of Engineering,
Amravati, India
²- PG Student M. Tech. (Structural Engineering), Applied Mechanics Department,
Government College of Engineering, Amravati, India
khante.suraj@gcoea.ac.in
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ABSTRACT

Seismic base isolation is an earthquake resistant design method that is based on decreasing the seismic demand instead of increasing the seismic capacity. In this paper, the effect of mass asymmetry in symmetric and asymmetric building is studied. To study the effect of torsion in seismic behavior of base isolated structures, a symmetric and asymmetric thirteen story concrete building is chosen as reference model. These models with mass eccentricity of 5%, 10%, 15% and 20% of greatest dimension of building in unidirection and bidirection are considered. The response spectrum and linear time history analysis of this eccentric model of fixed base and base isolated building using ETABS software is done. The symmetric and asymmetric fixed base and base isolated building having eccentricity in plan are compared for parameters such as maximum shear force, torsion, bending moment, lateral displacement, storey drift, storey acceleration and base shear. It is concluded that base isolation is very effective for various mass eccentric models. Response of base isolated mass eccentric model even in large mass eccentricity reduces as compared to fixed base building.

Key word: Base isolation, mass eccentricity, time history analysis, asymmetry, torsion.

1. Introduction

Seismic isolation is an old design idea, proposing the decoupling of a structure or part of it, or even of equipment placed in the structure, from the damaging effects of ground accelerations. One of the goals of seismic isolation is to shift the fundamental frequency of a structure away from the dominant frequencies of earthquake ground motion and fundamental frequency of the fixed-base superstructure. The other purpose of an isolation system is to provide an additional means of energy dissipation, thereby reducing the transmitted acceleration into the superstructure. This innovative design approach aims mainly at the isolation of a structure from the supporting ground, generally in the horizontal direction, in order to reduce the transmission of the earthquake motion to the structure. Thus, the base isolation essentially decouples the structure from the ground during earthquake excitation.

In buildings mass asymmetry is usually present at different floor level. This mass asymmetry may be due to water tank provided at top of building, any heavy weight machine placed at any level, etc. Due to this mass asymmetry in building center of mass is shifted from center of stiffness causing eccentricity. As this eccentricity increases, torsion in building also increases. There are only a few works available in the literatures where the torsional response of base isolated structures has been studied.
Hashemi et al. (2008), have examined the new method for control and reduction of torsion with base isolation. They studied the effect of torsion in seismic behavior of base isolated structure with 5%, 10%, 15% and 20% mass eccentricities in unidirection. Colunga and Soberon (2002) have presented the torsional response of base isolated structures when eccentricities are in the superstructure. Adibramezani et al. (2009) have presented the technique for the torsional response reduction of seismic isolated asymmetric structures with bidirectional eccentricities. Colunga (2007) has presented the torsional response of base isolated structures when unidirectional and bidirectional eccentricities are in the superstructure. Lee (1980) studied the effectiveness of bilinear hysteretic isolation systems in lowering the shear forces and torques generated in a single story structure having asymmetries in both horizontal directions. It is evident that literature studied the torsional response of base isolated structures having asymmetries in superstructures for low rise buildings i.e. one storey, three storeys, five storey building, etc. with limited parameters. In this paper the seismic response of fixed and base isolated building taking into account shifting of center of mass from center of stiffness due to mass distribution in symmetric and asymmetric building is studied. Thirteen storey symmetric and asymmetric building is modeled as fixed base and base isolated building with eccentricity in plan. The symmetric and asymmetric fixed base and base isolated building having eccentricity in plan are compared considering parameters such as maximum shear force, torsion and bending moment, lateral displacement, storey acceleration and base shear is done.

2. Building Model

The 13 storey symmetric building having unidirectional and bidirectional eccentricity in plan and 13 storey asymmetric building having bidirectional eccentricity in plan are modeled in ETABS software as a fixed base and base isolated building.

![Mass eccentric model of symmetric building](image1)

**Figure 1**: Mass eccentric model of symmetric building with (a) no eccentricity (b) unidirectional eccentricity (c) bidirectional eccentricity

![Mass eccentric model of asymmetric building](image2)

(a) No eccentricity  
(b) Bidirectional eccentricity
**Figure 2**: Mass eccentric model of asymmetric building with

Building has bottom storey height 2 m and other storey height is 3.2 m. The beams and column sizes are 0.3X0.5m and 0.45X0.45m. These building models associated with different studies are as follows

Model I: Fixed base with no eccentricity

Model II: Base isolation with no eccentricity

Model III: 5% Eccentricity with Fixed base in respective direction

Model IV: 5% Eccentricity with Base isolation in respective direction

Model V: 10% Eccentricity with Fixed base in respective direction

Model VI: 10% Eccentricity with Base isolation in respective direction

Model VII: 15% Eccentricity with Fixed base in respective direction

Model VIII: 15% Eccentricity with Base isolation in respective direction

Model IX: 20% Eccentricity with Fixed base in respective direction

Model X: 20% Eccentricity with Base isolation in respective direction

The building is symmetric in respect to stiffness and mass center has a shift relative to rigidity center to cause the eccentricity. ETABS is used to analyze the structure. The mass eccentric model of symmetric and asymmetric building is as shown in Figure 1 and 2. The gravity load obtained from static analysis of fixed base building to design the base isolators. The lead bearing isolator is designed for 13 storey base isolated symmetric and asymmetric building and modeled in ETABS software. The design properties of lead bearing isolators for 13 storey symmetric and asymmetric building are as shown in Table 1 and 2.

**Table 1**: Design of lead rubber bearing isolator for plan symmetric 13 storey building

<table>
<thead>
<tr>
<th>13 storey symmetrical bidirectional building</th>
<th>With no eccentricity</th>
<th>With unidirectional eccentricity</th>
<th>With eccentricity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal stiffness (Keff) (kN/m)</td>
<td>1849.24796</td>
<td>1899.47126</td>
<td>2111.3106</td>
</tr>
<tr>
<td>Pre elastic stiffness (K1) (kN/m)</td>
<td>16180.92</td>
<td>18473.97</td>
<td>16620.37</td>
</tr>
<tr>
<td>Vertical stiffness (Kv) (kN/m)</td>
<td>156800983.7</td>
<td>2.28E+08</td>
<td>2.39E+08</td>
</tr>
<tr>
<td>Yield force (F) (kN)</td>
<td>28.49</td>
<td>68.83333</td>
<td>76.51</td>
</tr>
<tr>
<td>Stiffness ratio</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Damping (%)</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
</tbody>
</table>
Table 2: Design of lead rubber bearing isolator for plan asymmetric 13 storey building

<table>
<thead>
<tr>
<th>13 storey symmetrical building</th>
<th>With no eccentricity</th>
<th>With bidirectional eccentricity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal stiffness (Keff) (kN/m)</td>
<td>1827.99963</td>
<td>2189.86501</td>
</tr>
<tr>
<td>Pre elastic stiffness (K1) (kN/m)</td>
<td>15995</td>
<td>19161.32</td>
</tr>
<tr>
<td>Vertical stiffness (Kv) (kN/m)</td>
<td>198476734.5</td>
<td>281533308.8</td>
</tr>
<tr>
<td>Yield force (F) (kN)</td>
<td>66.24333</td>
<td>79.35667</td>
</tr>
<tr>
<td>Stiffness ratio</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Damping (%)</td>
<td>0.05</td>
<td>0.05</td>
</tr>
</tbody>
</table>

3. Method of Analysis

For the analysis of fixed as well as base isolated building linear time history analysis and response spectrum method is used. To conduct time history analysis, Bhuj ground motion records are used. This earthquake is Bhuj which is as shown in Figure 3.

![Figure 3: Acceleration time history of Bhuj ground motion records](image)

4. Result and Discussion

Using ETABS software the fixed base and base isolated symmetric building with unidirectional and bidirectional eccentricity and fixed base and base isolated asymmetric building with bidirectional eccentricity are analyzed.

4.1 Maximum shear force

Maximum shear force in column of mass eccentric models of fixed and base isolated symmetric building for unidirectional and bidirectional eccentricity and fixed base and base isolated asymmetric building with bidirectional eccentricity are shown in Figure 4, 5 and 6. From Figure 4, it is observed that for symmetric building with unidirectional eccentricity maximum shear force in base isolated buildings of model II, model IV, model VI, model VIII, model X are decreased by 30%, 29%, 28%, 41%, 30% in comparison to fixed base buildings of model I, model III, model V, model VII, model IX.
From Figure 5 shows variation of maximum shear force for symmetric building with bidirectional eccentricity. It observed that for maximum shear force in base isolated buildings of model II, model IV, model VI, model VIII, model X are decreased by 25%, 35%, 33%, 27%, 24% in comparison to fixed base buildings of model I, model III, model V, model VII, model IX respectively. From Figure 6 shows graph for maximum shear force for asymmetric building with bidirectional eccentricity. It is observed that maximum shear force in base isolated buildings of model II, model IV, model VI, model VIII, model X are decreased by 25%, 28%, 24%, 27%, 12% in comparison to fixed base buildings of model I, model III, model V, model VII, model IX.

![Figure 4: Maximum shear force in column of mass eccentric models of fixed and base isolated symmetric building for unidirectional eccentricity](image)

![Figure 5: Maximum shear force in column of mass eccentric models of fixed and base isolated symmetric building for bidirectional eccentricity](image)

![Figure 6: Maximum shear force in column of mass eccentric models of fixed and base isolated asymmetric building for bidirectional eccentricity](image)

### 4.2 Torsion

The Maximum torsion in column of mass eccentric models of fixed and base isolated building for unidirectional and bidirectional eccentricity and fixed base and base isolated asymmetric building with bidirectional eccentricity are shown in Figure 6,7 and 8. From Figure 7, it is observed that for symmetric building with unidirectional eccentricity maximum torsion in base isolated buildings of model IV, model VI, model VIII, model X are decreased by 20%, 26%, 42%, 34% in comparison to fixed base buildings of model III, model V, model VII, model IX. From Figure 8, shows variation of maximum torsion for symmetric building with bidirectional eccentricity. It is observed that maximum torsion in base isolated buildings of model IV, model VI, model VIII, model X are decreased by 30%, 15%, 24%, 11%, 20% in comparison to fixed base buildings of model III, model V, model VII, model IX.
From Figure 9, shows graph for maximum torsion for asymmetric building with bidirectional eccentricity. It is observed that maximum torsion in base isolated buildings of model II, model IV, model VI, model VIII, model X are decreased by 30%, 34%, 12%, 25%, 11% in comparison to fixed base buildings of model I, model III, model V, model VII, model IX.

4.3 Bending moment

The maximum bending in column of mass eccentric models of fixed and base isolated building for unidirectional and bidirectional eccentricity and fixed base and base isolated asymmetric building with bidirectional eccentricity as shown in Figure 10,11 and 12. From Figure 10, it is observed that for symmetric building with unidirectional eccentricity maximum bending moment in base isolated buildings of model II, model IV, model VI, model VIII, model X are decreased by 25%, 33%, 31%, 42%, 45% of fixed base buildings in comparison to model I, model III, model V, model VII, model IX. From Figure 11, shows variation of maximum torsion for symmetric building with bidirectional eccentricity. It is observed that maximum bending moment in base isolated buildings of model IV, model VI, model VIII, model X are decreased by 34%, 12%, 25%, 11% in comparison to fixed base buildings of model III, model V, model VII, model IX.
From Figure 12, shows graph for maximum torsion for asymmetric building with bidirectional eccentricity. It is observed that maximum bending moment in base isolated buildings of model II, model IV, model VI, model VIII, model X are decreased by 16%, 18%, 32%, 32%, 13% in comparison to fixed base buildings of model I, model III, model V, model VII, model IX.

**Figure 10:** Maximum bending moment in column of mass eccentric models of fixed and base isolated symmetric building for unidirectional eccentricity

**Figure 11:** Maximum bending moment in column of mass eccentric models of fixed and base isolated symmetric building for bidirectional eccentricity

**4.4 Lateral displacement**

The floor level vs lateral displacement graph of mass eccentric models of fixed and base isolated symmetric building for unidirectional and bidirectional eccentricity and fixed base and base isolated asymmetric building with bidirectional eccentricity as shown in Figure 13, 14 and 15 respectively.

From Figure 13, 14 and 15, it is observed that in base isolated building the lateral displacements are observed more as compared to fixed base building and as the mass eccentricity increases in building the lateral displacement in various mass eccentric models also increases.
Figure 13 (a) and (b): Floor level vs lateral displacements graph for various eccentric conditions

Figure 14: Floor level vs lateral displacements graph for symmetric and various eccentric models of fixed base and base isolated asymmetric building for bidirectional eccentricity

4.5 Storey drifts

The floor level vs storey drifts graph of mass eccentric models of fixed and base isolated building for unidirectional and bidirectional eccentricity and fixed base and base isolated asymmetric building with bidirectional eccentricity are as shown in Figure 16, 17 and 18.
From Figure 12 and 13, it is observed that the base isolated building storey drifts are significantly reduced in comparison with the corresponding fixed base mass eccentric models for various unidirectional eccentricities.

**Figure 15:** Floor level vs storey drifts graph for various eccentric models of fixed base and base isolated symmetric building for unidirectional and bidirectional eccentricity

**Figure 16:** Floor level vs storey drifts graph for various eccentric models of fixed base and base isolated symmetric building for bidirectional and bidirectional eccentricity

From Figure 19, 20 and 21, it is observed that storey acceleration in base isolated building of mass eccentric model decreases by 60% of fixed base building of mass eccentric model and storey acceleration decreases as mass eccentricity increases. There is large difference from in storey acceleration for fixed base mass eccentric building model from

**Figure 17:** Floor level vs storey drifts graph for symmetric and various eccentric models of fixed base and base isolated asymmetrical building for bidirectional eccentricity

**4.6 Storey acceleration**

The floor level vs storey acceleration graph of mass eccentric models of fixed and base isolated building for unidirectional and bidirectional eccentricity and fixed base and base isolated asymmetric building with bidirectional eccentricity are as shown in Figure 19, 20 and 21. From Figure 19, 20 and 21, it is observed that storey acceleration in base isolated building of mass eccentric model decreases by 60% of fixed base building of mass eccentric model and storey acceleration decreases as mass eccentricity increases. There is large difference from in storey acceleration for fixed base mass eccentric building model from
bottom to top storey. In base isolated mass eccentric model the storey accelerations are nearly same from bottom to top storey.

![Figure 18](image1.png)  
**Figure 18:** Floor level vs storey acceleration graph for various eccentric models of fixed base and base isolated symmetric building for unidirectional eccentricity

![Figure 19](image2.png)  
**Figure 19:** Floor level vs storey acceleration graph for various eccentric models of fixed base and base isolated symmetric building for bidirectional eccentricity

![Figure 20](image3.png)

**Figure 20:** Floor level vs storey acceleration graph for symmetric and various eccentric models of fixed base and base isolated asymmetrical building for bidirectional eccentricity

### 4.7 Base shear

The time vs base shear graph of Bhuj earthquake of mass eccentric models of fixed and base isolated symmetric building for unidirectional and bidirectional eccentricity and fixed base and base isolated asymmetric building with bidirectional eccentricity are as shown Figure 22, 23 and 24.
Figure 21: Time vs base shear graph of Bhuj earthquake of mass eccentric models of fixed and base isolated symmetric building for unidirectional eccentricity

Figure 22: Time vs base shear graph of Bhuj earthquake of mass eccentric models of fixed and base isolated symmetric building for bidirectional eccentricity

Figure 23: Time vs base shear graph of Bhuj earthquake of mass eccentric models of fixed and base isolated asymmetric building for bidirectional eccentricity
The reduction in base shear for base isolated building for all is quite evident from figure 22, 23 and 24 for all unidirectional as well as bidirectional eccentricity and for symmetric as well as asymmetric buildings.

5. Conclusions

Following conclusions can be made from the analysis

1. From analytical results, it is observed that base isolation reduces the seismic response of all mass eccentric models in comparison to fixed base building and control the damages in building during strong ground shaking.

2. From the comparison between the mass eccentric model of base isolated and fixed base building, it has been observed that maximum shear force, torsion, bending moment, storey acceleration, base shear decreases whereas generally increases lateral displacements were observed for base isolated building.

3. From analytical study, it is observed that for all mass eccentric fixed base building have zero displacement at base of building whereas, In case of mass eccentric model of base isolated building appreciable amount of lateral displacements was observed at base. Also it has been observed that as floor height increases, lateral displacements increases drastically in fixed base building.

4. At base in mass eccentric model more storey drift observed for mass eccentric model of base isolated model compared to mass eccentric model of fixed base building. As storey height increases, the storey drifts in mass eccentric model of base isolated building drastically decreases as compared to mass eccentric model of fixed base building.

5. It is observed that for all mass eccentric fixed base building have zero storey acceleration at base of building whereas, in case of mass eccentric model of base isolated building appreciable amount of storey acceleration has been found out at base. Also it has been observed that as floor height increases, storey acceleration increases drastically in fixed base building as compared to base isolated building when it is almost constant.

6. Lateral displacement and storey drifts observed more in asymmetric building model of fixed base and base isolated building as compared with symmetric building model of fixed and base isolated building.

6. References


