Abstract
In past few years, passive control protective systems including base isolation systems are gaining large attention as mean to protect structures against seismic hazard. The base isolation system separates the structure from its foundation and primarily moves the natural frequency of the structure away from the dominant frequency range of the excitation via its low stiffness relative to that upper structure. In order to verify the effect of base isolation system, two different structures are presented as symmetrical and asymmetrical buildings in which the seismic responses of the 'fixed-base' and 'base-isolated' conditions have been compared using a well-known computer program ETABS2015 (version15.0.0). In this work (G+5) storey symmetrical and asymmetrical RC building is taken as to analyzed and designed. The aim of this study is to reduce the storey shear, storey drifts and storey acceleration due to earthquake ground excitation, applied to the superstructure of the building by installing base isolation devices at the foundation level and then to compare the different performances between the fixed base condition and base-isolated condition of symmetric and asymmetric building. All three basic seismic isolation system i.e. high damping rubber bearing (HDRB), lead rubber bearing (LRB) and friction pendulum system (FPS) have been used at the foundation level. Nonlinear dynamic (time history) analysis has been performed on Bhuj earthquake which intensity is 7.7 on the anniversary of India’s 51st Republic Day, 2001. In the second part of this study seismic response of combined or mixed isolation system (like HDRB & LRB, HDRB & FPS, FPS & HDRB) has presented for symmetric and asymmetric building. As far as the protection level is concerned, the seismic response of the structure on the mixed isolation system has been compared with that of the structure mounted on separately base isolation system, confirming the effectiveness of the base isolation system in terms of reduced structural responses under seismic loading. Comparing the results of the base-isolated condition with those obtained from the fixed-base condition has been shown that the base isolation system reduces the Storey shear, storey drifts and storey acceleration, also increasing the storey displacement and time period.
1. Introduction

The Indian subcontinent has a history of devastating earthquakes. The shaking memories of high intensity earthquakes of Bhuj (7.7) (on the anniversary of India’s 51st Republic Day, 2001) and Latur (6.2) (1993) are still live in our minds. Third deadliest earthquake in the history of the world, the Sumatra–Andaman earthquake, 2004 (9.3), and the tsunami generated thereafter, killed over 2,30,000 people in fourteen countries, including 15,000 people in India and inundating coastal communities with waves up to 100 ft height. Even now there is frequent occurrence of earthquakes in the Kashmir and Himalayan region. The major reason for the high frequency and intensity of the earthquakes is that the Indian plate is driving into Asia at a rate of approximately 47 mm/year. Geographical statistics of India show that almost 54% of the land is vulnerable to earthquakes. A World Bank & United Nations report shows estimates that around 200 million city dwellers in India will be exposed to storms and earthquakes by 2050.

The latest version of seismic zoning map of India given in the earthquake resistant design code of India [IS 1893 (Part 1) 2002] divides India into 4 seismic zones (Zone 2, 3, 4 and 5), with Zone 5 expects the highest level of seismicity whereas Zone 2 is associated with the lowest level. Each zone indicates the effects of an earthquake at a particular place based on the observations of the affected areas and can also be described using a descriptive scale like Modified Mercalli intensity scale or the Medvedev-Sponheuer-Karnik (MSK) scale. The MSK intensity broadly associated with the various seismic zones is VI (or less), VII, VIII and IX (and above) for Zones 2, 3, 4 and 5, respectively, corresponding to Maximum Considered Earthquake (MCE). Zone 5, which is referred to as the Very High Damage Risk Zone in the IS code, assigns zone factor of 0.36 to it, which is indicative of effective (zero period) peak horizontal ground accelerations of 0.36 g (36% of gravity) that may be generated during MCE level earthquake in this zone. The state of Kashmir, the western and central Himalayas, the North-East Indian region and the Rann of Kutch fall in this zone.

The application of the base isolation techniques to protect structures against damage from earthquake attacks has been considered as one of the most effective approaches and has gained increasing acceptance during the last two decades. This is because base isolation limits the effects of the earthquake attack, a flexible base largely decoupling the structure from the ground motion, and the structural response accelerations are usually less than the ground acceleration [6]. Many comparative studies have revealed that the responses of the isolated structure are significantly smaller than the fixed base structure [2], [3], [4], [5], and [6]. Most of these studies compared the seismic demands (e.g. storey displacement, storey drift, storey acceleration and storey shear) for the two types of building structures, but only a limited number of studies investigated the responses of the isolated structure using high damping rubber (HDR) isolation with detailed procedures of the design of HDR. Skinner et al. [7] indicated that a base isolator with hysteretic force-displacement characteristics can provide the desired properties of isolator flexibility, high damping and force limitation under horizontal earthquake loads, together with high stiffness under smaller horizontal loads to limit wind-induced motions.

Kelly [8] gave a brief introduction to the response mechanisms of base isolated buildings through two degrees of freedom linear system. The effectiveness of the isolation system to mitigate the seismic response is through its ability to shift the fundamental frequency of the system out of the range of frequencies where the earthquake is strongest. Also, Skinner et al. [7] demonstrated that...
the most important feature of seismic isolation is that its increased flexibility increases the natural period of the structure. Because the period is increased beyond that of the earthquake, resonance is avoided and the seismic acceleration response is reduced.

2. Modelling of 3D Building And Design Data

At present the six storied symmetric and asymmetric R.C.C. building is modelled and nonlinear dynamic analysis (i.e. Time-history analysis) is carried out and response of the buildings are calculated.

2.1 Modelling Approach

Three dimensional nonlinear time history analysis is carried out with the ETABS 2015 v15.0.0 software program. The building has square plan dimensions of 20m x 20m area and slab is modelled as a rigid diaphragm. Comparisons of results are given for the (G+5) storey building which is taken as an application example for this study. The model building is analyzed in the nonlinear time history analysis both for fixed base situation and also by earthquake protection alternatives such as isolators. The nonlinear time history analysis is carried out by considering Bhuj time history data. Comparison between the fixed base and the base isolated structure is carried out and the parameters such as storey shear, modal period, storey displacement, storey drift and storey acceleration are compared using ETABS 2015 v15.0.0.

2.2 Design Data

Buildings representing regular and irregular buildings are considered in this study. For the present study, structures of (G+5) stories are chosen. These structures are designed according to Indian Standards. The details of structure are considered to all regular and irregular buildings shown below in table 2.2.1.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Specifications</th>
<th>Dimensions/Data</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Grade of concrete</td>
<td>M25</td>
</tr>
<tr>
<td>2</td>
<td>Grade of steel</td>
<td>Fe415</td>
</tr>
<tr>
<td>3</td>
<td>Floor to floor height</td>
<td>3.2m</td>
</tr>
<tr>
<td>4</td>
<td>Plinth height above GL</td>
<td>1.5m</td>
</tr>
<tr>
<td>5</td>
<td>Parapet height</td>
<td>1.2m</td>
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<tr>
<td>6</td>
<td>Slab thickness</td>
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<tr>
<td>7</td>
<td>External wall thickness</td>
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</tr>
<tr>
<td>8</td>
<td>Internal wall thickness</td>
<td>115mm</td>
</tr>
<tr>
<td>9</td>
<td>Size of columns</td>
<td>300mm width x 500mm depth</td>
</tr>
<tr>
<td>10</td>
<td>Size of beams</td>
<td>300mm width x 400mm depth</td>
</tr>
<tr>
<td>11</td>
<td>Live load on floor</td>
<td>3 kN/m²</td>
</tr>
<tr>
<td>12</td>
<td>Live load on roof</td>
<td>1.5 kN/m²</td>
</tr>
<tr>
<td>13</td>
<td>Floor finish on floor</td>
<td>1.5 kN/m²</td>
</tr>
<tr>
<td>14</td>
<td>Floor finish on roof</td>
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<tr>
<td>15</td>
<td>Density of concrete</td>
<td>25 kN/m³</td>
</tr>
<tr>
<td>16</td>
<td>Density of brick masonry</td>
<td>20 KN/m³</td>
</tr>
</tbody>
</table>
2.3 Building Geometry

The structural analysis program, ETABS 2015 Version (15.0.0) was used to perform analyses. Regular building and irregular building of (G+5) storey is selected for presented study.

2.3.1 Regular (Symmetric) Building

The plan of regular building and 3D elevation model is shown in figure 2.3.1.1.

![Figure 2.3.1.1: Plan of building and 3D elevation model](image)

2.3.2 Irregular (plan Asymmetric) Building

The plan of C shape plan irregularity building and 3D elevation model is shown in figure 2.3.2.1.

![Figure 2.3.2.1: Plan of building and 3D elevation model](image)
2.4 Models considered for analysis

Symmetric and asymmetric (G+5) storey RC buildings was isolated at its base using three types of isolation systems discussed above. First we used the HDRB as the only device (let’s call it BI-HDRB), then we used the LRB (BI-LRB) and finally the FPS (BI-FPS). The isolation devices designed for it using the UBC-97 (UBC, 1997) requirement. As a first remark it is evident from the geometric characteristic (size) of isolators that the BI-LRBs will cost more than the other buildings, and this must be taken into account. A nonlinear time history analysis using ETABS2015 (v15.0.0) (Computers and Structures, 2015) assuming the Bhuj (India) record was carried out for all structure.

Plan of symmetric and asymmetric (G+5) storey RC buildings with separately mounted & different combinations of isolators showing in figure 2.4.1 & figure 2.4.2 respectively are as follows:

**FIXED**: Plan of building with fixed base

**HDRB**: Plan of building with High Damping Rubber Bearing

**LRB**: Plan of building with Lead Rubber Bearing

**FPS**: Plan of building with Friction Pendulum System Bearing

**Model 1A**: Plan of building with Combinations of HDRB & LRB i.e. HDRB on external column base and LRB on internal column base

**Model 1B**: Plan of building with Combinations of HDRB & LRB i.e. LRB on external column base and HDRB on internal column base

**Model 2A**: Plan of building with Combinations of HDRB & FPS i.e. HDRB on external column base and FPS on internal column base

**Model 2B**: Plan of building with Combinations of HDRB & FPS i.e. FPS on external column base and HDRB on internal column base

**Model 3A**: Plan of building with Combinations of FPS & LRB i.e. FPS on external column base and LRB on internal column base

**Model 3B**: Plan of building with Combinations of FPS & LRB i.e. LRB on external column base and FPS on internal column base

![Figure 2.4.1: Symmetric building plan of different combinations of isolators considered](image-url)
3. Results and Discussions

3.1 Results of Symmetric building

- Time Period

From figure 3.1.1, it is observed that the time period in all 9 models is increased more than 45% compared to fixed base. But FPS increases the time period compared to other combinations. In combinations, Model 2B & Model 3A more increases as compared to other combinations.

- Storey shear

From figure 3.1.2, it is observed that storey shear in X-direction is reduced in all 9 models as compared to fixed base, but storey shear more reduced in HDRB & in combinations model 1B as compared to others. Same conclusion is made for storey shear in Y-direction for figure 3.1.3.
• **Storey Displacement**

From figure 3.1.4 & 3.1.5, it is observed that the storey displacement in X & Y-Direction is increased for the all 9 models when compared with fixed base. But in case of FPS is more increased with other models. In Combinations, model 2B & model 3B is more increased.
Figure 3.1.4: Storey Displacement in X-Direction

Figure 3.1.5: Storey Displacement in Y-Direction

- Storey Drift

Figure 3.1.6: Storey Drift in X-Direction
From figure 3.1.6 & 3.1.7, it is seen that the storey drift in X & Y-Direction is reduced in all 9 models compared with fixed base.

- **Storey Acceleration**
  
  From figure 3.1.8 & 3.1.9, it is shown that the story acceleration in X & Y-Direction is reduced in all 9 models when compared with fixed base.
3.2 Results of asymmetric (Irregular) building

- **Time Period**

![Figure 3.2.1 Time period](image)

From figure 3.2.1, it is observed that the time period in all 9 models is increased more than 45% compared to fixed base. But FPS increases the time period compared to other combinations. In combinations, Model 2B & Model 3A more increases as compared to other combinations.
• Storey shear

From figure 3.2.2, it is observed that storey shear in X-direction is reduced in all 9 models as compared to fixed base, but storey shear more reduced in HDRB & in combinations model 1A as compared to others. Same conclusion is made for storey shear in Y-direction for figure 3.2.3.

• Storey Displacement
From figure 3.2.4 & 3.2.5, it is observed that the storey displacement in X & Y-Direction is increased for the all 9 models when compared with fixed base. But in case of FPS is more increased in Y-direction with other models. In Combinations, model 2B & model 3B is more increased in X-direction.

- **Storey Drift**

From figure 3.2.6 & 3.2.7, it is seen that the storey drift in X & Y-Direction is reduced in all 9 models compared with fixed base.
- **Storey Acceleration**

From figure 3.2.8 & 3.2.9, it is shown that the story acceleration in X & Y-Direction is reduced in all 9 models when compared with fixed base.

![Storey Acceleration in X-Direction](image)

![Storey Acceleration in Y-Direction](image)

### 4 Conclusions

In this work, Performance of Base Isolation System on (G+5) storey RC regular building and irregular building having plan irregularity such a ‘C’ shaped buildings have been done by using non-linear time history analysis. Three different isolation systems *i.e.* HDRB, LRB & FPS have investigated when mounted separately and when mounted in combination. By analyzing the structure using non-linear time history analysis method, it is concluded that:

i.) From analytical results, it is observed that base isolation reduces the seismic response of symmetric and asymmetric buildings when mounted separately and when mounted in combination in comparison to fixed base building and control the damages in building during strong ground shaking.
ii.) From the comparison between all 9 model of base isolated and fixed base building, it has been observed that storey shear, storey drift, storey acceleration decrease whereas generally increases time period, lateral displacements were observed for base isolated building.

iii.) It is concluded that the reduction of storey shear is more in HDRB and in combination HDRB & LRB i.e. MODEL 1A for symmetric and asymmetric building.

iv.) It is concluded that, the storey drift is reduced in all 9 isolation models but the reduction of storey drift is more in HDRB as compared to LRB & FPS.

v.) It is concluded that, the storey acceleration is reduced in all base isolators but in HDRB, it is more reduced as compared to LRB & FPS.

vi.) Increase in storey displacement is observed for bottom storey then gradually decreases for top storey of base isolated building as compared with fixed base building.

vii.) It is observed that fixed base building have zero displacement at base of building whereas, all base isolated building models shows increase in amount of lateral displacements at base. Also it has been observed that as floor height increases, lateral displacements increases drastically in fixed base building as compare to base isolated building. Due to this reduction in lateral displacement during earthquake damages of structural as well as non-structural is minimized.

viii.) At base more increasing storey drift is observed for all base isolated models as compared to model of fixed base building. As storey height increases, the storey drift in all base isolated building models drastically decreases as compared to model of fixed base building.

ix.) It is observed that combined isolation system helps to increase time period & storey displacement and to decrease storey shear, storey drift and storey acceleration.

x.) When isolators are arranged that inner and outer column at base in plan of building such a combination of HDRB&LRB, HDRB&FPS and FPS&LRB, it is observed that in combination of HDRB&FPS and FPS&LRB, when FPS is placed on outer column at base i.e. Model 2B & Model 3A are more effective as compared to other combination models.

5. References


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