Mitigation of Earthquake Responses Using SMA Supplemented Base-Isolation Devices for Benchmark Building

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Shape Memory Alloy (SMA), Benchmark building, Base isolation systems, Structural control, Near-field earthquake, Time-history analysis, SMA supplemented bearings, Isolation systems.

Abstract
The efficiency of traditional isolation bearings is doubted for near-field earthquakes because these bearings undergo large displacement. A comparative study of different base isolation systems of base-isolated benchmark building is carried out in the present study. The study is based on assumption that buildings are bi-directionally acted upon by near-field earthquakes for assessing their relative performance in seismic control of the benchmark building. The time history variations of important response parameters and evaluation criteria of the benchmark building has been studied for assessing the effectiveness of the isolation systems. The Shape Memory Alloy (SMA) is utilized with elastomeric bearings and friction bearings to study the effectiveness of SMA wires with different isolators. The benchmark building is modelled as a discrete linear elastic shear structure having three degrees of freedom at each floor level. Time domain dynamic analysis of this building has been carried out with the help of constant average acceleration Newmark’s method and equilibrium of non-linear forces has been taken care by fourth order Runge-Kutta method.

The comparative performance of various isolation systems has been studied with uniform and hybrid combinations. The hybrid combination of SMA supplemented bearings works out the better isolation system keeping in view of the percentage reduction in evaluation criteria for smart base-isolated benchmark building. Furthermore, it is shown that, the functionality of SMA wire is not efficient with Lead Rubber Bearing system, as it is able to control displacement but increases the acceleration, base shear, story drift and isolation forces.

1. Introduction

It is established that, in the catastrophic event such as an earthquake, the use of isolators at the base of a building significantly changes transfer of frequency content of ground to the superstructure and mitigates devastating effects of earthquakes. This however, highly depends on which isolation system is adopted for a particular building. The isolation systems designed for the building are broadly classified into elastomeric type and friction type. The elastomeric bearing consists of rubber like material which makes them flexible enough (and hence less stiff) for horizontal excitations. With the provision of steel shims in alternate layers, the vertical stiffness increases for elastomeric bearing for carrying vertical weight of the superstructure, are widely under stress.

The lead core is sometimes introduced at the centre of elastomeric bearing, which is then called as Lead Rubber Bearing (LRB) or New Zealand (NZ) bearing. The purpose of lead core is twofold. First is to give enough strength in horizontal direction in the event of minor ground tremors or wind like vibrations, and the second is to help in increasing hysteretic damping, thereby increasing energy dissipation. Jangid (2003) [1].

Literature review indicates past studies done about various isolation systems used for buildings and demonstrated in Park et.al. (2002) [2], Su et.al. (1989a) [3], (1989b) [4], Filiatrault and Cherry (1988) [5]. It shows use of traditional isolator bearings and combinations thereof. However, use of SMA with traditional bearings such as elastomeric bearings, friction bearing etc. are still in nascent stage which need more investigation. In this study, the use of SMA with elastomeric bearing, lead rubber bearing, friction pendulum bearing, R-FBI bearing and their hybrid combinations thereof are investigated. The benchmark building as adopted by Narasimhan et. al. (2006) [6] is used and modelled as lumped mass building having three degrees of freedom at each floor level. Time domain dynamic analysis of this building is carried out with constant average acceleration Newmark’s method.

The nonlinear SMA forces are modelled using Graesser-Cazzarelli (1991) [7] model with the help of fourth order Runge-Kutta method. So, various isolation systems have been proposed to obtain effective control over the structural response and the isolator displacement of a base-isolated benchmark building. By comparing them, conclusions about the merits and demerits of various proposed systems can be done. Therefore, the aim of the present study is (i) to compare and find the effects of different proposed SMA supplemented isolation devices with elastomeric and friction bearings for base isolated structure, (ii) to know the behaviour of SMA with ERB, LRB, FPS, RFBI bearings on the seismic performance of base-isolated benchmark building, (iii) to find effective and better isolation system for benchmark building, (iv) To know functionality of SMA with traditional bearing systems.

2. Modelling of Base Isolated Benchmark Building

The orientation and placement of isolation devices in a building decides the seismic resistance of the building and governing of its structural response. To investigate the effectiveness of an isolation system, a base-isolated benchmark building has been selected for analysis. Four different types of traditional bearings such as ERB, LRB, FPS and RFBI have been chosen for the present study. Well-defined analytical benchmark problems have been developed for studying response control strategies for building and bridge structures subjected to seismic excitation, by broad consensus effort of the American Society of Civil Engineers (ASCE) structural control committee. Narasimhan et. al. (2006) [6] have developed the smart base-isolated benchmark problem, based on input from the ASCE structural control committee. With the capability to model three different kinds of base isolation systems: linear elastomeric systems with low damping or supplemental high damping, frictional systems,
The floor plan of the building is L-shape up to the sixth floor and rectangular shape for remaining floors. The overall plan of the building is 82.4 m long and 54.3 m wide. The superstructure steel frame is mounted on a concrete base slab. The concrete base slab is considered as a three-dimensional linear elastic structure. The total weight of the superstructure is 203113.4013 kN. In this study, the isolation system of all the isolation bearings in the response of the base-isolated building. Therefore, it is considered that the SMA does not deform beyond its maximum strain limit due to the adopted distribution. The SMA supplemented isolation bearings can be modelled individually or globally by equivalent lumped elements at the centre of mass of the base.

The non-linear behavior of SMA is modelled using the Graesser-Cozzarelli model, and the forces in the bearings are transformed to the centre of mass of the building. All the SMA supplemented isolation bearings can be modelled individually or globally by equivalent lumped elements at the centre of mass of the base. The governing equation of motion for the base is written as

\[ [r]^T[M_b][\ddot{x}_b] + [r][F_b] + [m_b][\dot{x}_b] + \{F_s\} = 0 \]  

(2)

where \([m_b]\) is the diagonal mass matrix of the base mass of size 3 x 3; \([F_b]\) is the vector containing forces of isolation device \((\text{SMA} + \text{ERB})\) of size 3 x 1; and \([r]\) is the influence coefficient matrix of size 24 x 3.

The equations of motion of base isolated structure are solved numerically using Newmark’s method of step-by-step integration. The linear variation of acceleration over a small time interval, \(\delta t = 0.001s\) is considered.

3. SMA Supplemented ERB (SMA) Isolation System

SMA is used along with ERB isolation device for the need of zero residual deformation. The primary work of horizontal flexibility and vertical stiffness is provided by ERB. ERB consists of steel and rubber material in alternate layers. The steel shims provide high vertical stiffness which helps to control the rocking effects of the structure due to vertical vibrations caused by the earthquake. SMA is used along with the ERB due to its super-elasticity and damping capabilities which minimize the peak and residual isolator deformation. The SMA is wound along the corners of the building to provide hysteretic damping and also to add lateral stiffness. The SMA is used along with the ERB due to its super-elasticity and damping capabilities which minimize the peak and residual isolator deformation.
\[ K_b = \sum_{i=1}^{n} k_{bi} \]  
\[ K_t = \sum_{i=1}^{n} k_{ti} \]

are the resultant stiffness of the ERB and SMA devices, respectively.

The isolation period, \( T \) is defined follows

\[ T_b = 2\pi \sqrt{\frac{M}{K_b + K_t}} \]

where \( M \) is the total lumped mass of superstructure and base mass.

The damping coefficient of the \( i^{th} \) bearing is expressed as

\[ c_{bi} = 2m_i\omega_b \zeta_b \]

in which, \( m_i \) is the mass of superstructure and base mass on the \( i^{th} \) isolation device; \( \zeta_b \) is damping ratio of the ERB; and \( \omega_b \) is the isolation frequency defined as

\[ \omega_b = \frac{2\pi}{T_b} \]

It is to be noted that the \( \omega_b \) and \( T_b \) represents the fundamental frequency and time period of base-isolated structure if superstructure behaves rigidly. However, due to flexibility of superstructure the actual fundamental frequency and time period may slightly deviate from the above values.


SMA can be used for seismic resistant applications but very limited attempts are made in this regard as suggested by Wilson and Wesolowsky (2005) [8]. The two main properties of SMA are shape memory effect and superelasticity. While shape memory effect is achieved through thermal gradient induced transformation, the superelasticity is achieved through stress induced transformation. The phase transformation of SMA is achieved by applying load on it. This is achieved only at temperature greater than \( A_f \). The shape memory effect is not useful in base isolation. SMA manufacturers provide required materials which are used in available temperature ranges as given by Ozbulut and Harlebaus (2010) [9], Ozbulut et.al. (2011) [10]. In this study, it is assumed that temperature to cause superelasticity effect is available at ambient temperature. There are many models developed by the researchers such as Graesser – Cozzarelli (1991, 1994) [7, 11], Wilde et.al. (2000) [12], Ren (2007) [13]. In this work, Graesser – Cozzarelli (G – C) model is used. This model can implement both superelasticity and shape memory effect, Ghodke and Jangid (2016) [14]. Equations of force-deformation relationship which represents the super-elasticity of SMA to obtain a nonlinear force for the \( i^{th} \) SMA device are given as

\[ f_{sxi} = k_{ai} \left[ u_{xi} - u_{a} \frac{f_{sxi} - \beta_{xi}}{F_{yxi}} \right] ^{n-1} \left( f_{sxi} - \beta_{xi} \right) \]
\[ f_{syi} = k_{ai} \left[ u_{yi} - u_{a} \frac{f_{syi} - \beta_{yi}}{F_{yxi}} \right] ^{n-1} \left( f_{syi} - \beta_{yi} \right) \]
\[ \beta_{xi} = a_xk_{ai} \left( u_{xi} - \frac{f_{sxi}}{k_{ai}} + f_{sxi}u_{a} \right) erff(a'u_{a}) \]
\[ \beta_{yi} = a_yk_{ai} \left( u_{yi} - \frac{f_{syi}}{k_{ai}} + f_{syi}u_{a} \right) erff(a'u_{a}) \]

where \( n \) is a constant controlling the sharpness of transition of hysteresis while loading changes its nature; \( \beta_{xi} \) and \( \beta_{yi} \) are the back stress in \( x \) and \( y \) directions, respectively.

Figure 2. Mathematical models and force-displacement diagrams of a) SMA, b) ERB, c) N-Z d) FPS, and e) R-FBI isolators
\(a\) is the ratio of transformation to austenite stiffness of SMA; \(c'\) is a constant controlling the slope of the unloading path; \(f_i\) is a constant controlling the type and size of hysteresis; \(a'\) is a constant controlling the amount of elastic recovery during unloading; \((\cdot)\) is the ordinary time derivative; erf \((\cdot)\) is the error function of the argument \((\cdot)\).

6. SMA Supplemented Friction Pendulum System (SMAFPS) Isolation System

In FPS system, frictional force is proportional to the mass of the structure, and the centre of mass and centre of resistance of the sliding support coincides. Consequently, the torsional effects produced by the asymmetric building are diminished. The mathematical model and ideal force-deformation behaviour of the isolator is shown in Fig. 2 (d). In this study, the SMA wires are used along with FPS bearing system. Hence contribution by SMA is added in order to get total frictional force in SMAFPS in \(x\) and \(y\) directions as

\[f_{xi} = k_{si}u_{xi} + \mu_\omega Z_{xi} + f_{si}\]

\[f_{yi} = k_{si}u_{yi} + \mu_\omega Z_{yi} + f_{yi}\]

where \(\mu\) is the friction coefficient; \(\omega_i = m_i g\) is the weight of the structure and base on the \(i\)th isolator; \(Z_{xi}\) and \(Z_{yi}\) are hysteretic dimensionless parameters governed by Equation 19; \(k_{si}\) is the bearing stiffness provided by virtue of inward gravity action at the concave surface. The system is characterized by the isolation time period \((T_i)\) that depends upon the radius of curvature of the concave surface and the friction coefficient \(\mu\). The isolation stiffness, \(k_{si}\), is adjusted such that the specified value of the isolation period is achieved.

7. SMA Supplemented Resilient Bearing (R-FBI) Isolation System

Resilient friction base isolator (R-FBI) system is characterized by concentric layers of Teflon-coated plates in friction contact with each other, and a central rubber core. Mostaghel and Khodaverdian, (1987) [19]; Mostaghel and Mortazavi, (1991) [20]. The mathematical model and ideal force-deformation behavior of the bearing is shown in Fig. 2 (e). The SMA are used in combination with R-FBI and therefore the resisting forces in the SMAFSP isolation system in \(x\) and \(y\) direction are given as

\[f_{xi} = k_{si}u_{xi} + c_{si}\dot{u}_{xi} + \mu_\omega Z_{xi} + f_{si}\]

\[f_{yi} = k_{si}u_{yi} + c_{si}\dot{u}_{yi} + \mu_\omega Z_{yi} + f_{yi}\]

where \(Z_{xi}\) and \(Z_{yi}\) are hysteretic dimensionless parameters governed by equation 19 as given in Lead Rubber (N-Z) Bearing; \(f_{si}\) and \(f_{yi}\) are as calculated in equation 10 and 11, respectively.
8. Earthquake Ground Motions

The earthquake ground motion has peaks of acceleration in positive as well as negative values and also has various amplitudes and occur at various time intervals without any regular pattern. In this study, only horizontal motions have been considered in the benchmark problem. The historical ground motions given in benchmark problem have been considered in this study. Out of these, most of the earthquakes are near-fault. Jangid and Kelly (2001) [21] investigated that near-fault earthquakes have a significant impact on base-isolated buildings. It is established that base-isolated buildings have large residual deformations when it is subjected to near-fault earthquake. Near-fault earthquakes have long period pulses, large ground displacement, and permanent ground displacement. These earthquakes are applied bi-directionally in such a way that the fault normal (FN) and fault parallel (FP) directions of the earthquake are along the x and y directions of the benchmark building, respectively. Details of these ground motions are given in Table 2.

Table 2. Details of Earthquake Ground Acceleration Records

<table>
<thead>
<tr>
<th>Serials</th>
<th>Earthquake</th>
<th>Year</th>
<th>Station</th>
</tr>
</thead>
<tbody>
<tr>
<td>EQTH1</td>
<td>Imperial Valley</td>
<td>19.05.1940</td>
<td>El Centro</td>
</tr>
<tr>
<td>EQTH2</td>
<td>Kobe</td>
<td>16.01.1995</td>
<td>JMA</td>
</tr>
<tr>
<td>EQTH3</td>
<td>Northridge</td>
<td>17.01.1994</td>
<td>Sylmar</td>
</tr>
<tr>
<td>EQTH4</td>
<td>Northridge</td>
<td>17.01.1994</td>
<td>Newhall</td>
</tr>
</tbody>
</table>

9. Evaluation Criteria

The Table 3 shows performance evaluation criteria. The response quantities are normalized by corresponding uncontrolled response values as given in Table 4. Table 5 shows comparison between various isolation systems. The first eight cases in Table 5 are for uniform isolation types and last four are for hybrid combination of isolation type. The evaluation criteria as given in benchmark problem, is adopted in this study which is based on both peak and RMS responses of the building as tabulated in Table 3. In this Table 3, $V_b$ = Base and Structural shear, $F_b$ = Isolation force; RMS = Root mean square. $\dot{d}_f$ = Base and Structural shear, $V_s$ = Corresponding uncontrolled response quantity $a_t$ = top floor acceleration; $d_f$ = Inter story drift, $t$ = Time; $\| \cdot \|$ = Modulus of Vector magnitude; The relative performance of different isolation systems is evaluated based on the response values of corresponding uncontrolled fixed based structure. Hereinafter, these response values of Table 4 are called as uncontrolled response values. The selected seven earthquake time histories (EQTH) as applied to fixed based structure, gives large difference in peak acceleration values. This indicate that selected seven EQTH are having different characteristics.
Figure 7. Variation of Normalized Peak Absolute Acceleration for different Earthquakes and Isolation Types

Figure 8. Variation of Normalized Peak Absolute Acceleration for different Earthquakes and Isolation Types

Figure 9. Variation of Normalized Peak Base Displacement for different Earthquakes and Isolation Types

Figure 10. Variation of Normalized Peak Base Displacement for different Earthquakes and Isolation Types

Table 4. Uncontrolled response values

<table>
<thead>
<tr>
<th>EQ</th>
<th>TH</th>
<th>Dir Acct</th>
<th>Maxi m Base Shear (kN)</th>
<th>Maxi m Story Shear (kN)</th>
<th>Maxi m Base Displ. (m)</th>
<th>Maxi m Story Drift (m)</th>
<th>Maxi m Absol. Acceleration (m/s²)</th>
<th>Maxi m RMS Absolute Acceleration (m/s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TH 1</td>
<td>FP</td>
<td>6760</td>
<td>7438</td>
<td>1</td>
<td>0.02</td>
<td>7.87</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>TH 2</td>
<td>FN</td>
<td>2173</td>
<td>2246</td>
<td>60</td>
<td>0.09</td>
<td>27.09</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>TH 3</td>
<td>FP</td>
<td>2665</td>
<td>2687</td>
<td>50</td>
<td>0.08</td>
<td>28.07</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>TH 4</td>
<td>FN</td>
<td>1695</td>
<td>1993</td>
<td>80</td>
<td>0.05</td>
<td>17.80</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>TH 5</td>
<td>FP</td>
<td>1436</td>
<td>1444</td>
<td>70</td>
<td>0.04</td>
<td>14.06</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>TH 6</td>
<td>FN</td>
<td>1984</td>
<td>2014</td>
<td>10</td>
<td>0.07</td>
<td>24.17</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>TH 7</td>
<td>FP</td>
<td>1222</td>
<td>1246</td>
<td>85</td>
<td>0.03</td>
<td>22.74</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

* The responses like displacement and isolation force for fixed-base structure is irrelevant; hence the value is considered as unity.

*EQTH: Earthquake Time History

Table 5. Different Isolation systems considered for the Study

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Group</th>
<th>Isolation Type</th>
<th>Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Uniform Elastomeric Isolation System</td>
<td>92 ERB</td>
<td>ERB</td>
</tr>
<tr>
<td>2</td>
<td>92 ERB with SMA</td>
<td>SMARB</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Uniform Friction Isolation System</td>
<td>92 FPS</td>
<td>FPS</td>
</tr>
<tr>
<td>4</td>
<td>92 FPS with SMA</td>
<td>SMAF</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Hybrid Isolation System</td>
<td>61 ERB + 31 SMARB</td>
<td>HSMARB</td>
</tr>
<tr>
<td>6</td>
<td>61 LRB + 31 SMARB</td>
<td>HSMANZ</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>61 FPS + 31 SMARB</td>
<td>HSMAR</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>61 RFBI + 31 SMARB</td>
<td>HSMARF</td>
<td></td>
</tr>
</tbody>
</table>

10. Numerical Study

The different base isolation systems models with SMA are studied, mathematically modeled in MATLAB and its performance is compared through normalized peak structural performance evaluation criteria and time history variations of top floor absolute accelerations; base displacement; story drifts and base shears under the bi-directional excitations of four strong earthquakes. As shown in Table 4 the complete base isolation systems are basically divided into three parts, viz uniform elastomeric isolation system, uniform friction isolation system and hybrid isolation system. Each consisting of four cases each, thus comprising total 12 cases of isolation system. The time history analysis of the benchmark building has been conducted using proposed SMA supplemented isolators which are compared with traditional isolators. The total of 92 isolators are required for uniform isolation system of benchmark building. It is established that hybrid isolation is effective in reducing the superstructure displacement; Monzon et. al. (2012) [22]. Hence, an attempt is made here to study hybrid isolation system which consists of bearing combinations of 31 SMA + Each 61 (ERB, LRB, FPS, R-FBI) isolation systems.
The arrangements of bearings are shown in Fig. 1 (a). Four strong earthquakes under bidirectional excitations as tabulated in Table 2 are selected for checking performance of the seismic response of the base-isolated benchmark building. The earthquake ground motions are applied bi-directionally such that the fault normal (FN) and fault parallel (FP) directions of earthquakes are applied in x and y directions of the structure respectively. The performance of different isolation systems are compared on the basis of time history responses and reduction in percentage in evaluation criteria (as tabulated in Table 3). The results so obtained are tabulated in Table 6. Due to space unavailability, the comparison of only ERB, SMARB and HSMARB is shown. The time history variations of top floor acceleration, base-displacement, story-drift between base-slab and first-floor and base-shear in both x directions are plotted for various uniform and hybrid base-isolation systems as tabulated in Table 5. The base shear time history plot in Fig. 3 shows reduction in base shear values up to 50% for HSMARB as compared to traditional isolators. The story-drift between base slab and first floor time history plot (Fig. 4) shows difference between traditional isolators and SMARB isolators and it is worthwhile. One can observe lower values of story drifts at peaks for SMARB as compared to traditional isolators. Zero residual displacement is clearly seen.

Fig. 5 to Fig. 8 shows variation of normalized peak acceleration with different earthquakes and isolation types. It is found that SMARB and HSMARB gives less peak acceleration as compared to traditional bearings. Fig. 9 to Fig. 13 shows variation of normalized peak base displacement with different earthquakes and isolation types, as listed in Table 2 and Table 5, respectively. It is demonstrated that SMARB and HSMARB gives less displacement than other traditional bearings. It is concluded that HSMARB outperforms other than traditional bearings and combinations thereof.

The time variation of the absolute accelerations of top floor have been plotted in x direction, in Fig. 13 (a) for the isolation systems as mentioned in Table 5 and for Sylmar earthquake. Also it is compared with fixed base responses for the same Sylmar earthquake. In this Fig.13 (a), red dotted line corresponds to the fixed base response which is reduced by all the three isolation cases.

However, the reduction in response corresponding to SMARB (represented by magenta line) is appreciable compared to other traditional isolators. It is also observed that SMARB shows reduction in acceleration as compared to traditional ERB. There is little difference between hybrid and uniform combinations of the isolation systems with respect to acceleration. Table 6 shows the comparison of performance evaluation criteria values for various uniform and hybrid isolation system. The SMARB isolation system increases the acceleration values by 7-22% than the ERB system except for Sylmar earthquakes. But, HSMARB system increases the acceleration values only up to 5 – 8%.

### Table 6. Comparison of ERB, SMARB and HSMARB system in different earthquakes

<table>
<thead>
<tr>
<th>Isolation Type</th>
<th>J1</th>
<th>J2</th>
<th>J3</th>
<th>J4</th>
<th>J5</th>
<th>J6</th>
<th>J7</th>
<th>J8</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERB</td>
<td>0.37</td>
<td>0.37</td>
<td>0.37</td>
<td>0.37</td>
<td>0.37</td>
<td>0.37</td>
<td>0.37</td>
<td>0.37</td>
</tr>
<tr>
<td>SMARB</td>
<td>0.24</td>
<td>0.24</td>
<td>0.24</td>
<td>0.24</td>
<td>0.24</td>
<td>0.24</td>
<td>0.24</td>
<td>0.24</td>
</tr>
<tr>
<td>HSMARB</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
</tr>
</tbody>
</table>

The –ve and +ve sign values inside the brackets indicate percent increase and reduction, compared to traditional ERB case, respectively.

Figure 12. Variation of Normalized Peak Base Displacement for different Earthquakes and Isolation Types.

28
In Fig. 13 (b), base displacement time history response is shown. As clearly seen in Fig. 5, reduction in base displacement is better with SMARB. SMARB shows 41% reduction in base displacement as compared to ERB; whereas HSMARB shows 51% reduction. There is negligible difference in base displacement reduction using SMANZ and HSMANZ as compared to SMARB and HSMARB. In uniform friction based isolation system, uniform SMARF shows 33% reduction in base displacement as compared to uniform FPS whereas hybrid combination HSMAF shows 36% reduction in base displacement. Thus, it is proved that addition of SMA in traditional isolators is beneficial from reduction in seismic response point of view.

11. Concluding Remarks

This study emphasizes the effectiveness of using smart materials for base isolation and therefore the following conclusions are made.

- The seismic response control using SMA with traditional isolators is proved effective for base isolated benchmark building.

- The bearing displacements reduced effectively using SMA supplemented bearings. The structural response also improved better than traditional bearings.

- The hybrid isolation system having combination of SMA + ERB system is proved to be excellent among other combinations of traditional isolation systems.

- The hybrid isolation system having combination of SMA + Lead Rubber Bearing (LRB) is not so effective in seismic response control. It is able to control displacement but increases the acceleration, base shear, story drift and isolation forces. This is so because SMA and lead serves same purpose in bearings.

- The SMAF (having hybrid combination of SMA and Friction Pendulum System) performed better as compared to Reduced Friction Bearing Isolator (RFBI) combination with SMA with respect to control of isolator displacement.

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Declaration of Conflict of Interests

The author declares that there is no conflict of interest. The author has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.
References


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