# Seismic Base Isolation using Shape Memory Alloy

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## Abstract

The supplementation of shape memory alloy (SMA) to rubber bearing has been propounded to be a greater alternative to the conventional high damping rubber bearings (HDRB) under near-fault earthquakes. A comparison between responses of a building subjected to HDRB without SMA and with SMA is demonstrated for near-fault, far-fault and fling type of ground motions. The present study substantiates the significant reduction in the residual base isolator displacement and base shear of a multi storeyed building when subjected to SMA supplemented HDRB isolator under considered ground motions.

**Keyword- Base Isolation, Earthquake, High Damping Rubber Bearings, Shape Memory Alloy**

## I. INTRODUCTION

Seismic base isolation is thought of as a design approach in which the structure is protected from the risk of earthquake forces by a passive mechanism which alleviates the transmission of horizontal acceleration by detaching the superstructure motion from the ground. A unique class of smart materials, referred as shape memory alloys (SMA), has been tried to circumvent the problem of large bearing displacement by dissipating the input seismic energy. Several unique properties of SMA, such as considerable energy dissipation through large hysteresis loop and super-elasticity which refers to reduced peak displacements, makes it a promising choice in control application.

The performance of buildings isolated by shape memory alloy rubber bearings and comparison with the performance of conventional elastomeric bearing under near-fault earthquakes is demonstrated (Sourav G. et al. 2014). Results show that shape memory alloy rubber bearings reduce the peak displacements of the isolator considerably compared to the conventional lead rubber bearings (LRB).

It seems to be important to study the performance of SMA supplemented HDRB under near-fault, far fault and fling type motion in comparison with the conventional high damping rubber bearings (HDRB) which is investigated in this paper. The response evaluation for the isolated building is carried out by non-linear dynamic analysis under a set of recorded ground-motion time histories.

## II. MODELLING OF THE BUILDING WITH SHAPE MEMORY ALLOY RUBBER BEARING

### *A. Structural Model of the Base Isolated Building using SMARB*

A two-dimensional building frame, idealized as shear-type building, isolated by the SMARB and mechanical model of SMARB is shown in the figure 1(a) and 1(b) respectively. As the BI substantially alleviates the structural response, the superstructure behaviour can be assumed to be linear but behaviour of isolation bearing is highly non-linear. The structure is assumed to be excited by the horizontal component of earthquake ground motion only.

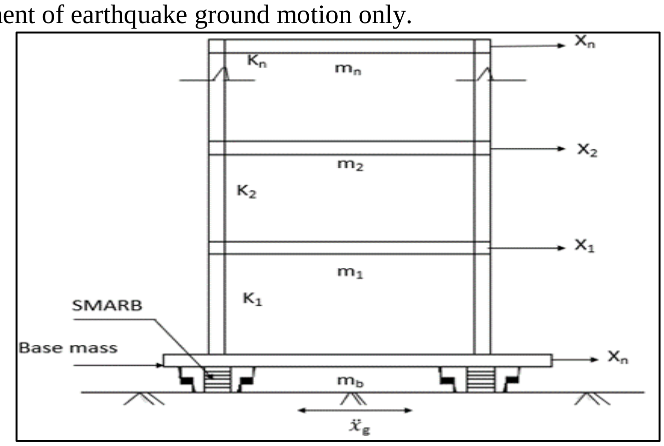



Fig. 1 (a): Idealized model of the base isolated building frame by shape memory alloy rubber bearing and (SMARB)

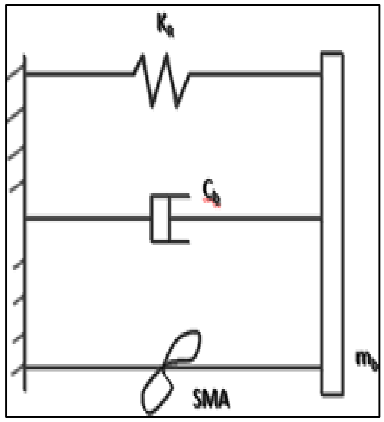



Fig. 1 (b): A mechanical idealization of SMARB

*B. Governing Equations of Motion*

The governing equations of motion for the N-storey superstructure model are expressed in the matrix form as,

$$[M]\{\ddot{x}\} + [C]\{\dot{x}\} + [K]\{x\} = -[M]\{r\}(\ddot{x}_g + \ddot{x}_b)$$

where, [M], [C] and [K] are the mass, damping and stiffness matrix of the fixed base structure respectively of the size n, {x} is the lateral floor displacement vector, {r} is the influence coefficient vector, x¨_b is the acceleration of bearing relative to ground, x¨_g is the earthquake ground acceleration.

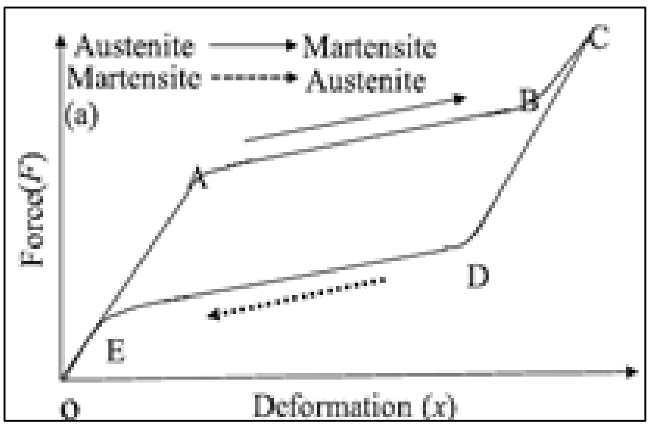



Fig. 2: Load-deformation behaviour of super-elastic SMA

The governing equations of motion for the isolator is written as,

$$m_b\ddot{x}_b + c_b\dot{x}_b + F_b - c_1\dot{x}_1 - k_1x_1 = -m_b\ddot{x}_g$$

where, $m_b$ is mass of the bearing and base, $F_b$ is the restoring force, $c_b$ is viscous damping of rubber, $k_1$and $c_1$ are stiffness and damping of first storey of the superstructure.

The restoring force of the isolator is expressed as $F_b(x_b) = k_R x_b + F_{SH}(x_b, \dot{x}_b)$

Where, $k_R$ is assumed elastic stiffness of rubber, $F_{SH}$ is the restoring force of SMA.

By combining equations of superstructure and isolator,

$$m_b\ddot{x}_b + c_b\dot{x}_b + k_R x_b + F_{SH} - c_1\dot{x}_1 - k_1x_1 = -m_b\ddot{x}_g$$

As the above equation involves non-linearity, the equation is solved numerically by Newmark's beta method.

## III. NUMERICAL STUDY

The present study evaluates the performance of SMA supplemented HDRB over the conventional HDRB for various near-fault, far-fault and fling step time histories.

| *Serials* | *Year* | *Earthquake* | *Magnitude* | *Station* | *PGA (g)* |
|---|---|---|---|---|---|
| *(a) Near-Fault Recordings (Forward-Rupture Directivity)* | | | | | |
| *1* | *1979* | *Imperial Valley* | *6.5* | *El Centro #5* | *0.37* |
| *2* | *1979* | *Imperial Valley* | *6.5* | *El Centro #7* | *0.46* |
| *3* | *1994* | *Northridge* | *6.7* | *Slymar* | *0.73* |

| | | | | | |
|---|---|---|---|---|---|
| *(b) Near-Fault Recordings (Fling-Step)* | | | | | |
| *1* | *1999* | *Chi-Chi* | *7.6* | *TCU052* | *0.44* |
| *2* | *1999* | *Chi-Chi* | *7.6* | *TCU068* | *0.50* |
| *3* | *1999* | *Chi-Chi* | *7.6* | *TCU074* | *0.59* |
| *(c) Far-Fault Recordings* | | | | | |
| *1* | *1994* | *Northridge* | *6.7* | *Canoga Park - Topanga Canyon* | *0.47* |
| *2* | *1994* | *Northridge* | *6.7* | *Northridge-Saticoy* | *0.53* |
| *3* | *1940* | *Imperial Valley* | *6.95* | *El Centro* | *0.31* |

*Table 1: Ground acceleration records selected for the study*

The performance of the building frame isolated by the SMA bearing is studied through numerical simulation to demonstrate the effectiveness of SMARB over HDRB. Graesser-Cozzarelli model of the building with SMA is implemented. SMA is wrapped around rubber bearing along the direction of ground motion. The viscous damping of the superstructure is taken as 2%. The mass ratio (ratio of the base mass ($m_b$) to the storey ($m_i$)) for the isolation bearing is considered as 1. The default value of the period is taken as 0.5 s. Numerical values selected for the parameters characterizing the force-deformation behaviour of the SMARB and the HDRB are provided in Table II. The response quantities of interest demonstrated here are the base shear and the peak displacements of the isolator. This is because the base shear quantifies the amount of force transmitted to the superstructure and thus is associated with the efficiency of isolation. The isolator displacement (if large) is also linked with the isolator damage, pounding and others.

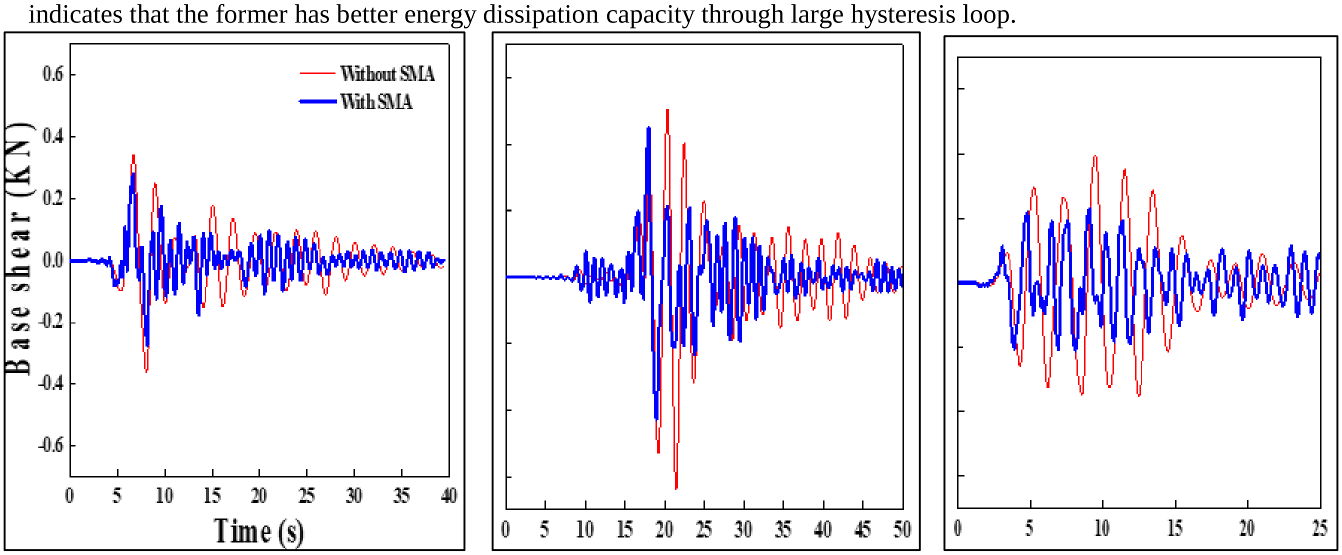
| *Superstructure* | *SMA* | *HDRB* |
|---|---|---|
| *T=0.5s*<br>*ξ=2%* | $T_b$=2s, $F_{S0}$=0.125, $\xi_b$=5%, $\alpha_s$=0.10, $u_{Ys}$=0.025 m, a=0.005 m, b=0.05 m $f_T$=0.07, c'=0.001, a'=2500, η=3 | $F_{L0}$=0.075 m<br>$\alpha_L$=0.05<br>$u_{YL}$=0.025 m |

*Table 2: Parametric values adopted for superstructures, SMARB and HDRB*

## IV. RESULTS AND CONCLUSION

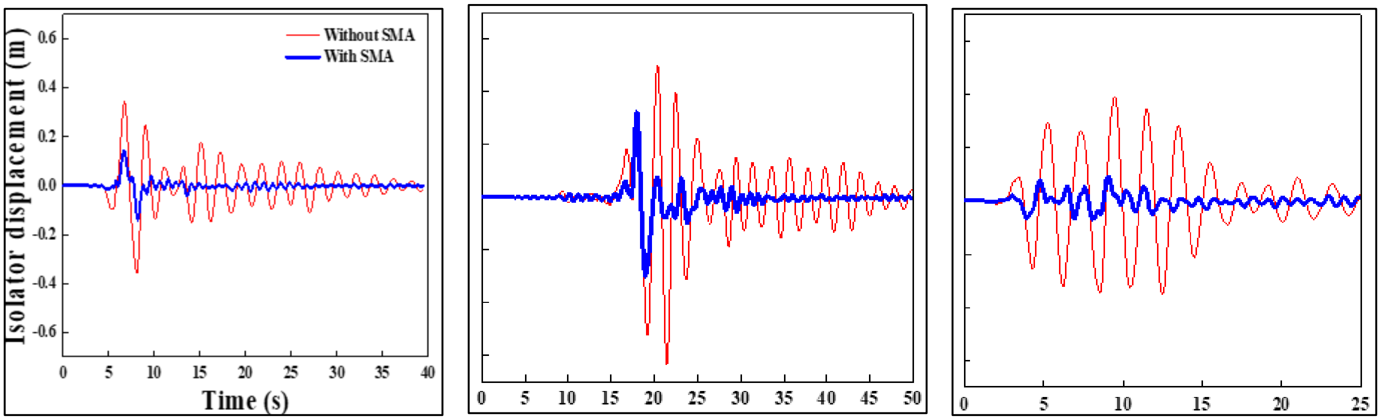
Shape memory alloy supplemented high damping rubber bearings are adopted for the response control of the base isolated building. Comparison between SMA without HDRB and SMA with HDRB as a base isolator is studied for near-fault, far-fault and fling step ground motions. The dynamic response quantities; base shear and isolator displacement, are considered for the present study. From the present trends of the study, the following conclusions can be drawn.

- The reduction in base shear using SMA with HDRB compared to SMA without HDRB for the considered earthquakes is 20% to 25% for near-fault, 15% to 30% for fling step and 30% to 40% for far-fault ground motions.
- Relative to HDRB, the reduction in isolator displacement is 40% to 60% for near-fault, 35% to 50% for fling step and 60% to 80% for far-fault ground motions.
- The hysteresis loop of considered ground motions for SMA with HDRB is broader than SMA without HDRB as isolator. This indicates that the former has better energy dissipation capacity through large hysteresis loop.




(a) (b) (C)

Fig. 3: Comparison of base shear for buildings having HDRB without SMA and with SMA supplemented HDRB under (a) Imperial Valley (El Centro #5, 1979) (b) Chi-Chi (TCU068, 1999) (c) Northridge (Canoga Park - Topanga Canyon, 1994) earthquake




(a) (b) (c)

Fig. 4: Comparison of isolator displacement for buildings having HDRB without SMA and with SMA supplemented HDRB under (a) Imperial Valley (El Centro #5, 1979) (b) Chi-Chi (TCU068, 1999) (c) Northridge (Canoga Park - Topanga Canyon, 1994) earthquake

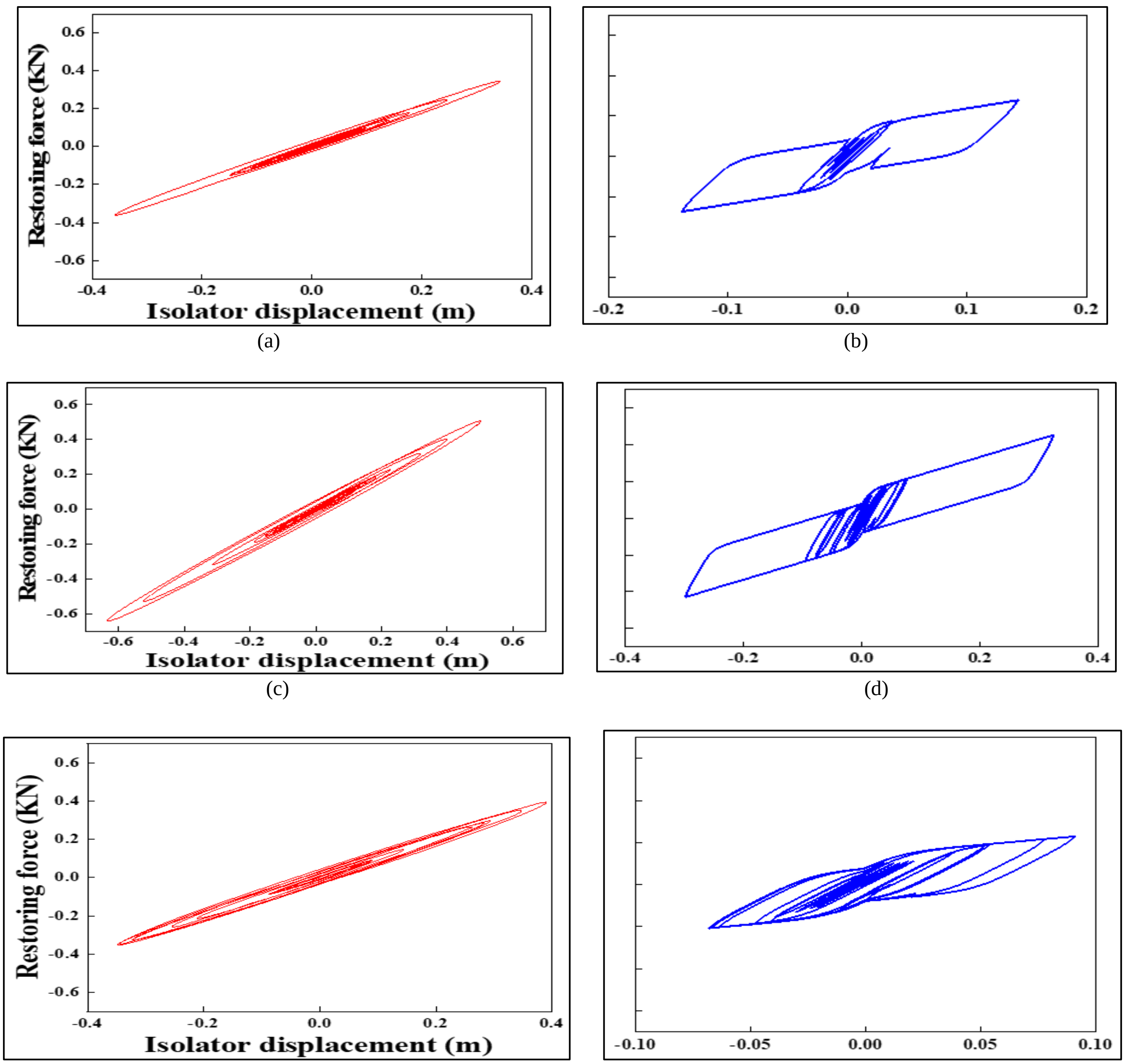



Fig. 5: Force-deformation hysteresis for (a) HDRB and (b) SMARB under Imperial Valley (El Centro #5, 1979), (c) HDRB and (d) SMARB under Chi-Chi (TCU068, 1999) and (e) HDRB and (f) SMARB under Northridge (Canoga Park - Topanga Canyon 1994) earthquake

| *Serials* | *Year* | *Earthquake* | *Station* | *Peak base shear* | | *% Variation in base shear* | *Peak isolator displacement* | | *% Variation in isolator displacement* |
|---|---|---|---|---|---|---|---|---|---|
| | | | | *HDRB* | *SMARB* | | *HDRB* | *SMARB* | |
| *(a) Near-Fault Recordings (Forward-Rupture Directivity)* | | | | | | | | | |
| *1* | *1979* | *Imperial Valley* | *El Centro #5* | *0.362* | *0.279* | *-23* | *0.358* | *0.142* | *-61* |
| *2* | *1979* | *Imperial Valley* | *El Centro #7* | *0.456* | *0.356* | *-22* | *0.451* | *0.223* | *-51* |
| *3* | *1994* | *Northridge* | *Slymar* | *0.624* | *0.488* | *-22* | *0.617* | *0.361* | *-42* |
| *(b) Near-Fault Recordings (Fling-Step)* | | | | | | | | | |
| *1* | *1999* | *Chi-Chi* | *TCU052* | *0.747* | *0.615* | *-18* | *0.739* | *0.493* | *-34* |
| *2* | *1999* | *Chi-Chi* | *TCU068* | *0.640* | *0.452* | *-30* | *0.634* | *0.323* | *-49* |
| *3* | *1999* | *Chi-Chi* | *TCU074* | *0.418* | *0.353* | *-16* | *0.412* | *0.220* | *-47* |
| *(c) Far-Fault Recordings* | | | | | | | | | |
| *1* | *1994* | *Northridge* | *Canoga Park - Topanga Canyon* | *0.393* | *0.229* | *-42* | *0.390* | *0.090* | *-77* |
| *2* | *1994* | *Northridge* | *Northridge-Saticoy* | *0.481* | *0.330* | *-32* | *0475* | *0.195* | *-59* |
| *3* | *1940* | *Imperial Valley* | *El Centro* | *0.186* | *0.206* | *11* | *0184* | *0.067* | *-64* |
| *Note: Negative sign indicates decrease and positive sign indicates increase in percentage values of SMARB in comparison with HDRB.* | | | | | | | | | |

*Table 3: Dynamic response quantities from HDRB and SMARB and its variation*

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