Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 52(3) (2020) 153-156
DOI: 10.22060/ceej.2018.14747.5731

Investigating the Effective Parameters on the Performance of Hybrid Lead Rubber Bearing with Shape Memory Alloy

R. Mahmoodi, H. Tajmir Riahi* , M.R. Zare

Faculty of Civil and Transportation Engineering, University of Isfahan, Isfahan, Iran.

ABSTRACT: In this paper, numerical analysis of the hybrid lead rubber bearing system with shape memory alloy was investigated by the finite element method using ABAQUS software and the effectiveness of various parameters on its performance was examined. The studied parameters were the bearing dimensions, type of shape memory alloy and its cross-sectional area, the lead core diameter, the thickness of rubber layers and the compressive stress applied on the bearing. In this hybrid bearing, shape memory alloy wires were used as a recovery unit and lead core was used as a unit for energy dissipation. For this purpose, a finite element model of the bearing was modeled using the Abaqus software and the effect of the various parameters mentioned on the bearing performance has been investigated. The results showed that this hybrid bearing has better seismic performance than lead rubber bearing. Finally, depending on what kind of performance is required from the bearing, its specifications can be obtained optimally.

Review History:

Received: 7/24/2018
Revised: 10/26/2018
Accepted: 10/28/2018
Available Online: 12/15/2018

Keywords:

Base isolation
Lead rubber bearing
Shape memory alloy
Passive control
Seismic performance

1. INTRODUCTION

Design methods and technologies for the implementation of earthquake resistant buildings have progressed dramatically in recent years. In the meantime, energy control and energy control systems, such as seismic isolation in buildings and bridges, have shown good performance against seismic hazards. Seismic isolation is one of the best ways to reduce the impact of earthquakes on structures by separating the horizontal motion of the structure from the ground motion. This separation is accomplished by adding horizontal flexibility and damping at the base of the structure [1].

Robinson et al. introduced a lead rubber bearing (LRB) in 1981. This bearing consists of rubber and steel layers as well as the lead core [2-4]. The lead core produces damping for LRB while rubber layers help LRB to restore its deformation. To decrease residual deformation of bearing, Dezfuli and Alam [5] examined two types of rubber bearings consisting of two different layouts of shape memory alloy (SMA) wires. They used SMA wires as additional elements that improve the performance of the bearing by increasing energy dissipation capacity and reducing residual displacements in large strains. They studied the effects of shear strain amplitude parameters, SMA type, bearing size ratio, wire diameter, and pre-strain level of wires. The results indicate that when rubber bearing with is subjected to a large shear strain range, the SMA wire with a super elastic strain of 13.5% is the best choice. The results show that the cross-sectional area of the wires is most effective parameter in reducing residual deformation. Dezfuli and Alam [6] also presented a theoretical model of LRB equipped with SMA wires. The results show that SMA restoration property decreases the residual deformation in the bearing.

Shape memory alloys are capable of returning to their original shape even in large deformations. These alloys have two austenite and martensite phases of performance. The austenite phase has a cubic structure and it is tight because of its high symmetry. The martensite phase can be twisted more easily. Its shape is monoclinic and less symmetrical than austenite. The martensitic phase is a thermostatic phase that has two characteristics of slippery and low energy, which changes with a small change in temperature and stress. Unless the alloy is cooled, in the absence of loading, the phase shift from austenite to martensite occurs, which is not the result of this phase change, which is macroscopic. As the material is heated in the martensite phase, the phase reversal occurs [7].

In this study, the lead rubber bearing with SMA wires has been studied. These wires are arranged in crosswise shape in two opposite directions, as shown in Figure 1.

2. METHODOLOGY

2.1 Verification

In order to carry out numerical analyses on the seismic performance of LRB equipped with SMA wires, it is necessary to first verify the accuracy of the numerical model. For this purpose, numerical models are verified using laboratory results. Since this type of bearing has not been investigated,

*Corresponding author's email: tajmir@eng.ui.ac.ir

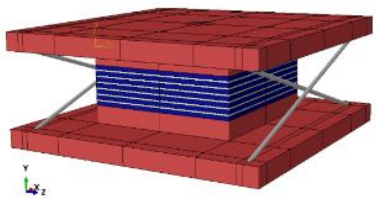
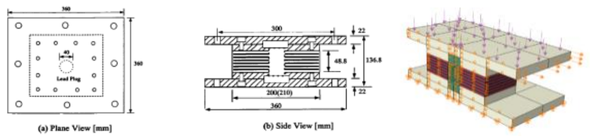


Figure 1. Hybrid LRB with SMA wires modeled in this study



a b

Figure 2. a) The size of the rubber and steel plates used in the tested bearing sample [8], b) LRB modeled in Abaqus

Table 1. Specifications of LRB

Bearing type	LRB
Sectional dimensions (mm)	200×200
Shear modulus (MPa)	0.78
Number of rubber layers	7
Thickness of rubber layers (mm)	5
Number of layers of steel	6
Thickness of a steel layer (mm)	2.3
Lead core diameter (mm)	40

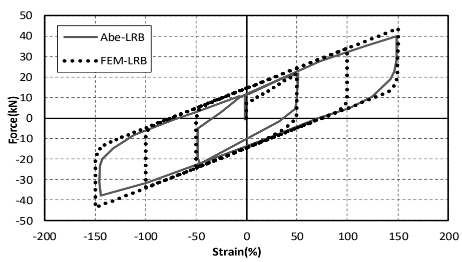


Figure 3. Comparison of hysteresis diagram for the bearing in this study with the Abe laboratory model

the verification for LRB and shape memory alloy is done individually.

2.1.1. LRB

Abe et al. [8] have conducted studies on a laboratory sample of LRB. Figure 2 and Table 1 show the bearing and the dimensions of its different parts, respectively.

Figure 2b illustrates the bearing modeled in Abaqus software. The rubber used in this bearing has low damping in the range of 2-3 percent. The Neo hook model [9] has been used for modeling. The Young modulus and yield stress of the lead core are 16 MPa and 10 MPa. This core is modeled as a bilinear model with kinematic plastic behavior. Steel plates are assumed to be isotropic material with a Young modulus of 210 MPa and a Poisson ratio of 0.3. A comparison of the hysteresis behavior of the numerical model with the laboratory sample in Figure 3 indicates the accuracy of numerical results.

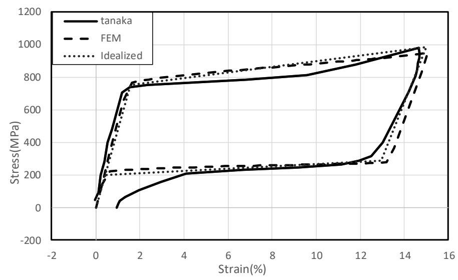


Figure 4. Stress-strain diagram of the shape memory alloy

Table 2. Specifications of the models

Bearing Specifications	How to change			
Dimensions (mm×mm)	200×200	250×250	30×300 0	-
Core diameter (mm)	40	70	100	-
Wire diameter (mm)	2.5	5	8	-
Number of rubber layers	7	8	9	11
Number of steel layers	6	7	8	10
Rubber Thickness (mm)	5	4.087	3.337	-
Thickness of steel (mm)	2.3	2.3	2.3	-
SMA type	1	2	3	
Vertical pressure (MPa)	7.84	3.456	4.97	11

2.1.2. Shape memory alloy

In this validation study, three types of shape memory alloy have been used. This sample is verified according to the research presented by Tanaka [7]. Figure 4 shows the results of the ideal stress-strain curve, Tanaka laboratory test results, and results of the Abaqus model [10]. The results show the proper fitting of numerical models with Tanaka experiment results.

3. MODEL SPECIFICATIONS

SMA wires are added to the LRB introduced in the

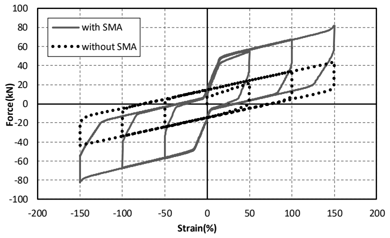


Figure 5. Hysteresis diagrams of the LRB and LRB-SMA

Table 3. Results of the LRB and LRB-SMA models

γ (%)	With SMA			Without SMA		
	50	100	150	50	100	150
Horizontal stiffness (kN/mm)	3.1	1.92	1.55	1.2	0.97	0.83
Residual deformation (mm)	8.79	11.5	12.3	17.38	26.3	26.3
Dissipated energy (J)	1503	3308	5080	993	2037	3054
Viscous damping (%)	25.1	22.4	18.9	41.4	27.1	21.2

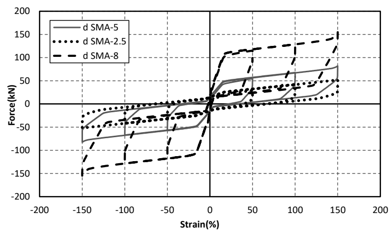


Figure 6. Hysteresis diagrams by changing the diameter of the wires

previous section and the effects of different parameters on the performance of this hybrid bearing have been investigated. In this study, 25 samples of LRB-SMA hybrid isolation systems have been analyzed using the static analysis method.

In this finite element model, the shear modulus of rubber is 0.7 MPa and its density is1200 kg/m^3. The boundary conditions are such that the lower steel plate is restrained in all directions. Because of bearing symmetry, half of the isolator is modeled and in the symmetry region, the model is restrained in the vertical direction.

Specifications of the parameters of the 25 models are presented in Table 2. Dimensional changes applied in this research are in accordance with the changes that Alam and Ahmadipour have done in their research [11]. Assuming that the wires are attached to the upper and lower steel plates of the bearing at the end, the ends of the wires and plates are tied together.

4. DISCUSSION AND RESULTS

4.1 Effect of adding SMA on LRB bearing behavior

In this section, the effect of adding SMA wires on the stiffness, dissipated energy capacity, residual deformation, and equivalent viscous damping of the bearing is discussed. Figure 5 shows the hysteresis diagram of the LRB model and the hybrid bearing of this study. As can be seen from this Figure, with the addition of SMA wires to LRB, the stiffness has increased. In Table 3, the values of the parameters presented before for the two LRB and LRB-SMA isolators are compared. The effects of increasing SMA wires diameter can be seen in Figure 6.

CONCLUSIONS

Results showed that hybrid bearing has better seismic performance than LRB. Depending on what kind of performance was required from the bearing, its specification can be obtained optimally. A summary of the results is as follows:

- With the addition of SMA wires to LRB, stiffness, yield force and dissipated energy capacity increase, and residual deformation decreases. By increasing the dimensions of the bearing, stiffness and yielding force increase, and residual deformation and equivalent viscous damping decrease. By increasing the cross-section of SMA wires, stiffness, yielding force and dissipated energy capacity increase and residual deformation decreases. By increasing the diameter of the lead core, stiffness, dissipated energy capacity, residual deformation, and equivalent viscous damping increase. In other words, by increasing the diameter of the lead core, hybrid bearing hysteresis behavior approaches LRB bearing behavior.

- In order to achieve a combination of behavior, both the appropriate absorption capacity of lead core and the SMA restoration property, it is necessary to establish an appropriate balance between the stiffness of the lead core and SMA wires.

- By increasing the height of the hybrid bearing, the bearing behavior varies for low to high shear strain. In other words, in high shear strains due to the large length variation of SMA wires, austenite phase changes to martensitic, which increases the stiffness, but in the lower shear strains, this is vice-versa.

- The change in the thickness of the rubber layers by keeping the height of the entire isolator constant and the change in the compressive stress applied to the isolator do not significantly change the behavior of the isolator.

REFERENCES

[1] F. Naeim and J. M. Kelly, Design of seismic isolated structures: from theory to practice. John Wiley & Sons, 1999.

[2] W. R. a. L. Greenbank, “n extrusion energy absorber suitable for the protection of structures during an earthquake,” Earthquake Engineering & Structural Dynamics, vol. 4, pp. 251-259, 1976.

[3] T. Kelly, “Base Isolation of Structures,” Design guidelines. Auckland: Holmes Consulting Group Ltd, 2001.

[4] W. H. Robinson, “Lead-rubber hysteretic bearings suitable for protecting structures during earthquakes,” Earthquake Engineering & Structural Dynamics, vol. 10, pp. 593-604, 1982.

[5] F. H. Dezfuli and M. S. Alam, “Shape memory alloy wire-based

smart natural rubber bearing," Smart Materials and Structures, vol. 22, no. 4, p. 045013, 2013.
[6] F. H. Dezfuli and M. S. Alam, "Hysteresis model of shape memory alloy wire-based laminated rubber bearing under compression and unidirectional shear loadings," Smart Materials and Structures, vol. 24, no. 6, p. 065022, 2015.
[7] Y. Tanaka, Y. Himuro, R. Kainuma, Y. Sutou, T. Omori, and K. Ishida, "Ferrous polycrystalline shape-memory alloy showing huge superelasticity," Science, vol. 327, no. 5972, pp. 1488-1490, 2010.
[8] M. Abe, Junji Yoshida, and Yozo Fujino, "Multiaxial behaviors of laminated rubber bearings and their modeling. I: experimental study," Journal of Structural Engineering, vol. 130, pp. 1119-1132, 2004.
[9] M. J. Asl, M. Rahman, and A. Karbakhsh, "Numerical Analysis of Seismic Elastomeric Isolation Bearing in the Base-Isolated Buildings," Open Journal of Earthquake Research, vol. 3, no. 01, p. 1, 2014.
[10] M. Conti et al., "Nitinol embolic protection filters: design investigation by finite element analysis," Journal of Materials Engineering and Performance, vol. 18, no. 5-6, pp. 787-792, 2009.
[11] M. Ahmadipour and M. S. Alam, "Sensitivity analysis on mechanical characteristics of lead-core steel-reinforced elastomeric bearings under cyclic loading," Engineering Structures, vol. 140, pp. 39-50, 2017.

HOW TO CITE THIS ARTICLE

R. Mahmoodi, H. Tajmir Riahi, M.R. Zare, Investigating the Effective Parameters on the Performance of Hybrid Lead Rubber Bearing with Shape Memory Alloy, Amirkabir J. Civil Eng., 52(3) (2020) 153-156.

DOI: 10.22060/ceej.2018.14747.5731