# Magnetorheological Elastomeric Base Isolator for Seismic Protection

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**Abstract -** *Base isolator is one of the most effective technique in decreasing earthquake force that transmits to the building However, conventional passive base isolators have to be provided with large seismic gaps due to their high horizontal flexibility and exhibits poor adaptability to varying ground excitations. Hence it becomes necessary to introduce "smartness", in the conventional base isolators and enhance their adaptability to varying spectra of input loads. As a new branch of rheological smart material, magnetorheological elastomer (MRE) can be controlled rapidly and reversibly by the application of magnetic field. Compared to MR fluid devices, MRE devices can provide tunable stiffness and damping without worrying about the leakage and settlement problems. Therefore, an increasing number of researchers have shown their interest to the material, and lots of innovative MRE devices have been proposed in recent years. The present study aims at proposing an innovative laminated model of magnetorheological elastomeric base isolator by conducting a finite element study on the laminated portion of the bearing and provide a design specification for the MRE isolators. Analytical results show that incorporation of magnetic particles into the elastomeric medium can increase the energy dissipation capacity of the isolator and it can bring out a significant reduction in the size of isolator during design phase.*

***Key Words*: Base Isolation, Magneto rheology, MRE Isolator, ABAQUS, Nonlinear Static Analysis**

## 1. INTRODUCTION

Base isolation is the isolation of structure from ground, so that only a small portion of seismic motions is transmitted up through the building. It is the decoupling of building from the foundation by increasing flexibility & providing adequate damping for the structure. This reduces the floor acceleration & inter storey drifts within the building.

Conventional passive base isolators are provided with large seismic gaps due to their high horizontal flexibility and they exhibit poor adaptability to varying ground excitations. They will not work if earthquake occurs at a frequency other than the designed one. So it is time to introduce "smartness", in the conventional base isolators and enhance their adaptability to varying spectra of input loads.

Magneto-Rheological Elastomer (MRE) based isolators, is a newly emerging type of smart isolator in which shear modulus and damping can be changed by a magnetic field in real-time. Thus, it instantly decouples incoming external excitations at any dominant frequency range from the structures. The MRE base isolator consists of sandwiched layers of MRE and steel plates surrounded by a solenoid.

Jolly et al [1] in 1996 conducted the first comprehensive investigation on MREs. They created a model to describe the MR effect as a function of particle magnetization. This model presented the modulus change of the composite with respect to the applied magnetic field. Since then, a number of researches has been done in this area.

Yancheng Li et al. (2013 a,b,c) [2] developed the first adaptive seismic isolator with laminated MREs and steel plates. This novel adaptive seismic isolator utilizes MREs for its field-sensitive material property. Experimental testing was conducted on a shake table facility under harmonic cycling loading. The results showed that the new MRE base isolator possesses a remarkable adaptive ability.

The Magneto rheological elastomer bearing (MREB) model considered by Shiwei et al. (2016) [3] consists of laminated MRE and steel layer kept above the iron core wounded by the coil. Both experimental and simulation data indicated that MRE's optimal particle volume fraction were related with MREB's input power. The MRE with 0.11 particle volume fraction would have the best performance for the proposed MREB with input power of 58.5W.

Yancheng Li and Jianchun Li (2015) [4] proposed an innovative magnetic circuit design for MRE base isolator with multi-layer of MRE materials. In the design, laminated MRE and steel structure was adopted as part of the magnetic core together with two steel blocks. Finite element results showed that such innovative magnetic design was able to provide sufficient and uniform magnetic field to all MRE layers.

### 1.1 Magneto Rheological Elastomers

Magneto-Rheological elastomers (MREs), a new addition to the Magneto-Rheological material family, are smart materials composed of an elastomeric matrix filled with magnetic particles. The presence of these magnetic particles allows the MREs to exhibit a magnetic field dependent material property i.e., a controllable shear modulus, stiffness and damping. The material regains its original property instantly as the magnetic field is removed.

MREs are typically prepared by curing process for polymers. The polymeric material (e.g. silicone rubber) in its liquid state is mixed with iron powder and several other additives to enhance their mechanical properties. The entire mixture is then cured at high temperature. Curing in the presence of a magnetic field causes the iron particles to arrange in chain like structures resulting in an anisotropic material. If magnetic field is not applied, then iron-particles are randomly distributed in the solid resulting in an isotropic material. Curing without magnetic field can greatly simplify the manufacture process, which is a significant advantage for manufacture in large quantities in industry. However, the isotropic MREs only have about half field-dependent modulus compared with anisotropic MREs.

## 2. MODELLING AND ANALYSIS OF BUILDING IN ETABS 2015

The building is modelled and analysed in ETABS 2015 and the results obtained are utilised for the initial design of the MRE isolator. A linear static analysis of the building is done in ETABS 2015 to obtain the critical column having maximum axial load. The fundamental mode of vibration and natural time period of vibration of the building is obtained from the response of the building which are the major inputs for preliminary design of the MRE isolator. The building considered for the study is a six storeyed (G+5) reinforced concrete building which is shown in fig 1.

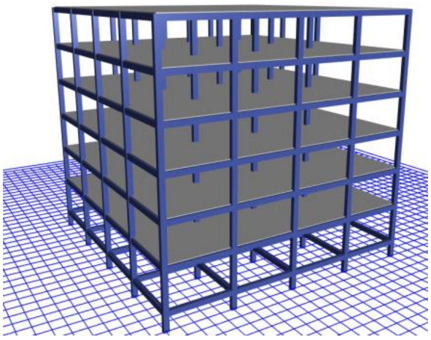

**Fig -1**: Geometry of the building modelled in ETABS 2015

Equivalent Static Analysis was conducted on the RCC building. The fundamental time period of the building obtained is 1.731s which is used for applying sinusoidal displacement on the model. The maximum axial load acting on the structure is 2660kN which is applied as an equivalent pressure on the top plate of the model. The maximum storey displacement of the RC building is 69.15mm which is less than permissible value and hence the building is safe.

## 3. PRELIMINARY DESIGN OF ISOLATOR

The isolator is designed to carry a vertical load of 2660kN, in seismic zone III with soil condition as medium soil. The shear modulus, $G_0$ is taken as 0.4 MPa for the rubber and the time period is fixed as 1.731sec for the Design Based Earthquake (DBE). The design was based on IS 1893:2002

The three basic steps in design procedure are as follows

1. To find thickness of the isolator
2. To find diameter of isolator
3. Layering of isolator

Both MRE and conventional isolators were designed and the dimensions are compared.

**Table -1:** Comparison of design

| **Dimensions** | **Conventional bearing** | **MRE Bearing** |
|---|---|---|
| Diameter | 910mm | 440mm |
| Total height | 308mm | 310mm |
| Thickness of MR layer | 23mm | 19mm |
| Thickness of steel | 2mm | 2mm |
| Number of MR layers | 10 | 12 |
| Number of steel layers | 9 | 11 |
| End plate diameter | 1000mm | 550mm |
| End plate thickness | 30mm | 30mm |

Design procedure for conventional and MRE isolator is same. The difference is in the shear modulus of the elastomer. Due to presence of Carbonyl Iron particles in MR Elastomer, the shear modulus of the elastomer is significantly higher than that of conventional isolator. This provides a reduced size for the MRE bearing than the later.

## 4. NON-LINEAR STATIC ANALYSIS OF CONVENTIONAL AND MRE ISOLATORS

For assessing the behaviour of conventional magnetorheological elastomeric bearings, a numerical evaluation for the compression and shear test is done in ABAQUS platform.

### 4.1 Geometry and Material Properties

Description of geometry of elements selected, the material properties provided, meshing, boundary conditions and loading provided are given below. [5]

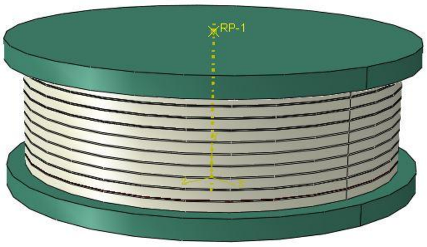

**Fig -2**: Modelled structure of conventional isolator

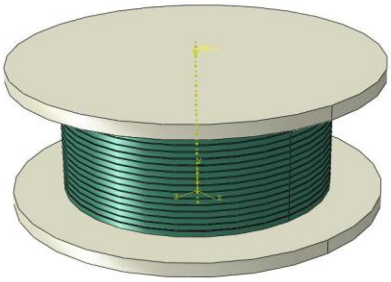

**Fig -3**: Modelled structure of MRE isolator

**Table -2:** Material properties of isolators

| | |
|---|---|
| **Conventional Elastomer** | 3rd order Ogden Model for elastomer<br>Viscoelastic parameters: Prony Stress Parameters |
| **MR Elastomer** | 3rd. order Ogden Model<br>Ogden parameters: For 40% Carbonyl Iron particle at 200mT magnetic field condition<br>Viscoelastic parameters: Prony Stress Parameters |
| **Steel layer** | Linear elastic and isotropic material<br>Youngs modulus, E = 2e+11 Pa<br>Poisons ratio = 0.3<br>Shear modulus, G = 7.6923e+10 Pa |

All the bottom nodes are restrained against rotation and translation. The maximum compressive load acting on the building was 2660kN which is applied as a concentrated force at the top surface of bearing along the Y direction. A lateral displacement in the X direction is applied as a sinusoidal cyclic load on the top surface node simulating earthquake which has a maximum amplitude of 110mm with a time period of 1.731s.

### 4.2 Results and Discussions

The following figures show the result of non-linear static analysis conducted on the conventional as well as the MRE bearing.

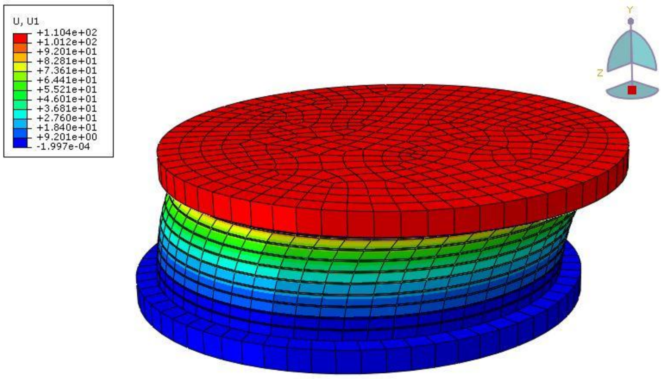

**Fig -4**: Deformation diagram of Conventional isolator

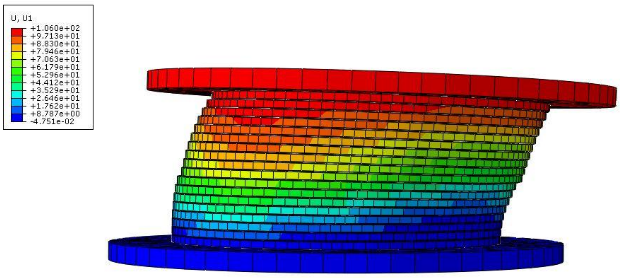

**Fig -5**: Deformation diagram of MRE isolator

The maximum displacement was found to be 110.43mm for conventional isolator and 106.02mm for MRE isolator. The isolators were also stable at the maximum displacement of 110.43mm and 106.02mm respectively.

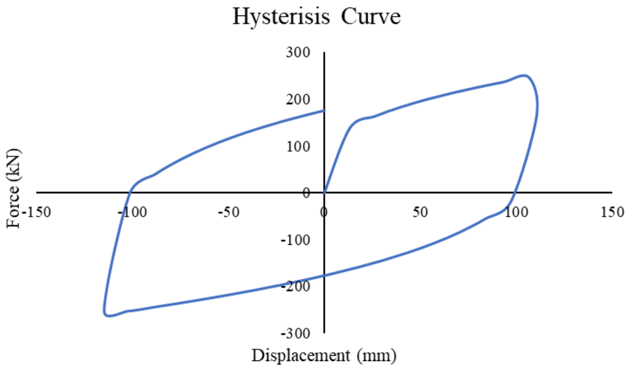

**Chart -1**: Energy Dissipation of conventional bearing

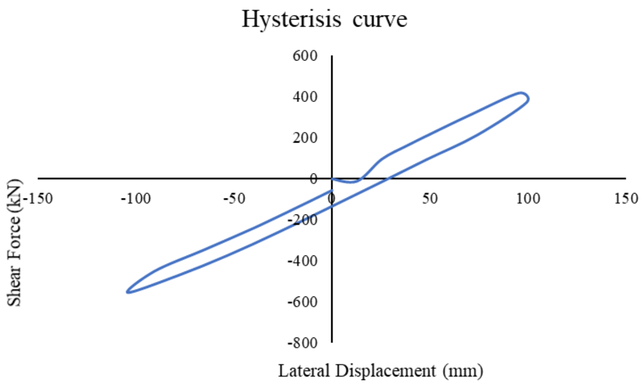

**Chart -2**: Energy Dissipation of MRE bearing

The shear force versus lateral displacement of the isolator which gives the energy dissipation capacity of the isolators. The energy dissipated by the conventional and MRE isolators were found to be 65.072kNm and 102.68kNm respectively.

**Table -3:** Comparison of MRE and Conventional isolators

| **Isolator Type** | **MRE** | **Conventional** |
|---|---|---|
| Max Shear Force (kN) | 546.5 | 253.52 |
| Energy Dissipated (kNm) | 102.68 | 65.072 |
| Effective stiffness (kN/m) | 4704.45 | 2226.1 |
| Equivalent damping (kNs/m) | 871.01 | 451.91 |
| Damping ratio | 0.336 | 0.168 |

It was seen that the modelling and analysis of the conventional and MRE isolators in ABAQUS software were successful. MRE isolator has better characteristics such as energy dissipation, effective stiffness, equivalent damping than that of conventional isolator and the damping ratio of MRE isolator was also found to be greater than that of conventional isolator. For a given load and time period, MRE isolators can take higher shear force than conventional elastomeric isolators. The increase in shear force is 58%. Higher energy dissipation capacity for MRE isolators than that of conventional elastomeric isolators indicates that MRE isolators have higher efficiency during seismic excitations. Effective stiffness of MRE isolators is about double than the conventional isolators. The equivalent damping of MRE isolators is 93% higher than that of conventional isolator. The damping ratio of MRE isolator is twice the conventional isolator.

## 5. PARAMETRIC STUDIES

The performance of MRE isolator can be evaluated to obtain the optimum configuration and dimensions which yields the best suitable base isolator for the RC building under consideration. The parametric studies to be conducted to obtain the optimum configuration are

- Configuration of layers
    - Thickness of rubber
    - Number of layers
- Variation with displacement

### 5.1 Configuration of layers

Since the height of MRE bearing is kept constant the thickness of rubber layers can be varied by adopting various shape factors for the isolator. Selected shape factors are s = 6,8,10,12

**Table -4:** Configurations of the isolator

| **Sl no** | **Designation** | **Shape Factor** | **Number of rubber** | **Thickness of rubber layers** | **Number of steel layer** | **Thickness of steel layers** |
|---|---|---|---|---|---|---|
| 1 | S6 | 6 | 12 | 19 | 11 | 3 |
| 2 | S8 | 8 | 15 | 14 | 14 | 3 |
| 3 | S10 | 10 | 20 | 11 | 19 | 3 |
| 4 | S12 | 12 | 22 | 10 | 21 | 3 |

**Table -5:** EDC for various configurations of isolator

| **Sl No** | **Designation** | **No of rubber layers** | **Thickness of rubber layers (mm)** | **EDC (kNm)** |
|---|---|---|---|---|
| 1 | S6 | 12 | 19 | 102.68 |
| 2 | S8 | 15 | 14 | 103.41 |
| 3 | S10 | 20 | 11 | 104.85 |
| 4 | S12 | 22 | 10 | 105.57 |

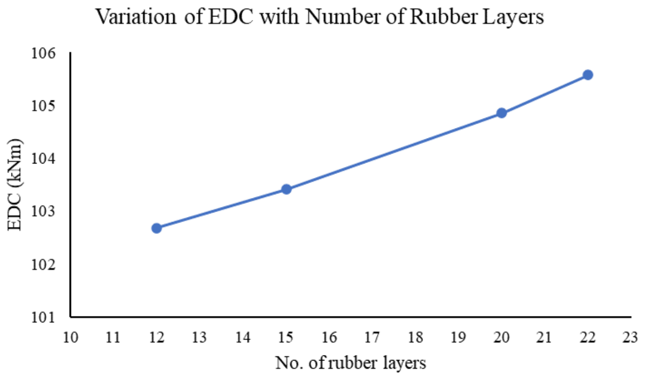

**Chart -3:** Variation of EDC with number of rubber layers

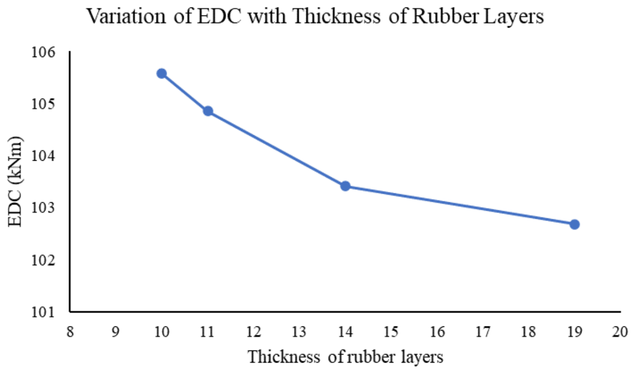

**Chart -4:** Variation of EDC with thickness of rubber layers

The above graph indicates that energy dissipation capacity of MRE isolator depends on the configuration of rubber and steel layers. As the number of rubber layers increases, there is an increase in EDC of the isolator though this increase is not highly significant. This increase is linear. The increase in thickness can decrease the EDC of the isolator. Maximum EDC obtained is 105.57kNm and is for a configuration with 10mm thick rubber layers and with 19 such layers. It is better to increase the number of layers of steel and rubber and also the thickness of rubber layers should be made minimum. It is also found that increase in thickness of steel layers does not contribute to any increase in energy dissipated by the isolator. Thickness of steel shims are kept to be 2mm.

## 5.2 Variation with Displacement

The model is analysed to find the behaviour of the isolator at various displacements. Horizontal displacement values are applied incrementally. Initially, displacement corresponding to 50% shear strain is applied. Displacement values are increased until maximum shear strain is reached. The displacements applied are 110mm, 130mm and 150mm

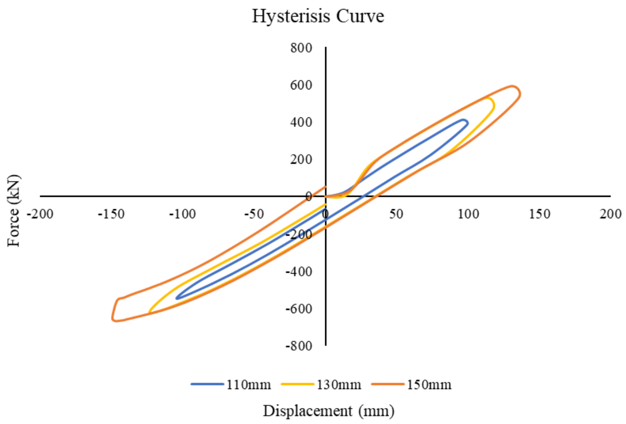

**Chart -5:** Hysteresis Curve generated for the model for displacements of 110mm, 130mm and 150mm

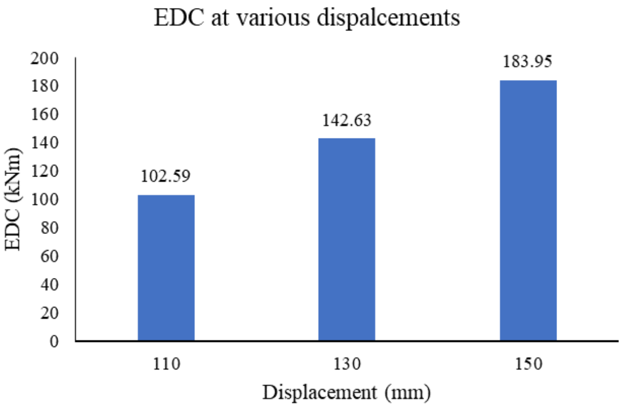

**Chart -6:** Energy Dissipated for various displacements

It was found that energy dissipation increased with increase in displacement and was found to be stable up to a displacement value of 150mm. a wider hysteresis curve was obtained for increased displacements which giver lager area under the hysteresis curve. The maximum shear forces acting at 110mm, 130mm and 150mm are 546.51kN, 623.81kN and 661.3kN respectively. The energy dissipation increased from 102.59kNm to 183.95kNm for increase in displacement from 110mm to 150mm. This indicate an increase of 79% in energy dissipation capacity when displacement increased to 150mm.

## 6. CONCLUSIONS

This study presents the modelling and finite element analysis of magnetorheological elastomeric bearing for base isolation. The study focussed on performance of the MRE bearing under various displacements and a comparison of the MRE bearing with conventional rubber bearing. ABAQUS 6.14 was used to analyse the bearing incorporating non-linear properties. Non-linear static analysis was conducted for all the bearings. Parametric studies were conducted to study the effect of bearing configuration and displacement on MRE isolators. The conclusions obtained can be summarized as follows:

- The effectiveness of MRE as seismic isolation is found to be higher than that of conventional isolator. Analysis shows that incorporation of magnetic particles in elastomer helps in adjusting the shear modulus and damping of isolator.
- Design of both conventional and MRE isolators was effective and it is found that MRE isolator can have a reduced size than that of conventional isolator for a fixed height.
- Energy dissipation of MRE isolators is found to be higher than that of conventional isolators.
- The effective stiffness, viscous damping and damping ratio of MRE isolators is higher than conventional isolators.

- The parametric studies show that with decreasing the thickness of rubber and increasing number of rubber layers results in increase in the energy dissipation capacity of MRE isolator
- Also, isolator was found to be stable up to a displacement of 150mm and increases the EDC of isolator with displacement
- There is an increase of 79% of the energy dissipation capacity of the isolator when displacement increased from 110mm to 150mm

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