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Steady compression characteristics of laminated MRE isolator

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Abstract. This paper focused on an experimental setup on laminated magnetorheological elastomer (MRE) isolator under steady state compression test. An isotropic type natural rubber (NR) based MRE were fabricated and layered with a steel plate to form a multilayer sandwich structure adopted from the conventional laminated rubber bearing design. A set of static compression test was conducted to explore the potential of semi-active laminated MRE isolator in field-dependent stiffness properties. Stress versus strain relationship was assessed under different magnetic fields application. Based on the examination, the stress altered as the application of magnetic fields. Consequently, the effective stiffness of isolator also influenced by the magnetic fields induction. The experimental results show that the proposed laminated MRE isolator can effectively alter the compression stiffness up to the 14.56%. The preliminary results have confirmed the tunability of the semi-active laminated MRE isolator in which it would be beneficial for improving building isolator in general.

1. Introduction

Magnetorheological elastomers (MREs) are solid analog of magnetorheological fluids. They consist of iron particles in nonmagnetic matrix materials having viscoelastic characteristics. These materials have rheological properties that can be changed continuously, rapidly, and reversibly by applying magnetic fields [1,2]. Hence, these unique properties of MRE have attracted many researchers to study and develop new vibration isolation system that utilized MRE material for vibration reduction in civil engineering and others application [3–7]. The MRE vibration isolation system with controllable stiffness and damping properties potentially can overcome the major shortcomings of the traditional base isolation system by shifting and avoiding the resonant frequency of the seismic excitations [3,8,9].

Currently, many researchers have proposed their design and tested to study the adaptability of smart MRE vibration isolator with various range of earthquakes wave [5,10–12]. However, the experimental test of MRE isolator is mainly limited to the horizontal movement and only focus on the shear performances of MRE isolator. For example, Usman et al. [5], reported the base isolation system using

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MREs have reduced the horizontal structural accelerations and storey drifts compared with the passive base isolation system under different earthquake inputs. Li et al. [11] in their study developed a highly adjustable MRE base isolator and the experimental results on the shear test shows the force and stiffness increase when have applied current. In another study, Eem et al. [12] evaluated the performances of smart base isolation system with different frequencies using shaking table system that gives horizontal movement on the scaled single-story building structure. From the study, the application of smart base isolation system can reduce the responses of the test structure by shifting the natural frequency of the structure. Furthermore, Behrooz et al. [10] examined the adaptability of semi-active variable stiffness and damping isolator (VSDI) on a scaled building system and the results demonstrate a reduction in both acceleration and displacement of the building structure. In theory, a structure should possibly isolate in both horizontal and vertical directions. Nevertheless, the performance of MRE isolator on vertical movement has not been fully explored, and most of the studies only focus on the shear performances of MRE isolator. This is because of the seismic effect was critical in the horizontal direction instead of vertical direction. Unfortunately, some structures that contained sensitive equipment or material such as at nuclear power plant and reactor buildings [13] clearly need vertical isolation system [14,15] to sustain the load from structures and vibration during an earthquake.

Therefore, this paper revealed the performances of laminated MRE isolator in term of stress-strain and stiffness properties during compression loading. The development of a laminated MRE isolator is presented in this paper including design, fabricating and testing of laminated MRE isolator. MRE based NR was utilized in laminated MRE isolator and evaluated using dynamic fatigue machine. The design concept of laminated MRE isolator was adopted from the conventional laminated rubber bearing. The MRE was layered with the steel plate to form the laminated structures that can sustain with large vertical loading from the structures. Magnetic coils are designed to provide sufficient magnetic field across the laminated MRE - steel. Furthermore, after MRE isolator fabrication, an experimental test was conducted to examine the performances of laminated MRE isolator in static compression under various magnetic field intensities.

2. Laminated MRE Isolator

The laminated MRE isolator design was divided into five main parts which are bottom and top plate, laminated structures, electromagnetic coils, housing and coils bobbin. The design concept of laminated MRE isolator has been modified from the conventional laminated rubber bearing by adding more steel plates and adding coil parts to generate magnetic circuits around the laminated MRE isolator. Some parameters need to be considered in designing the laminated MRE isolator to guide the magnetic flux. The selection of materials for each part in laminated MRE isolator, type of coil, thickness of MRE and steel plates are the parameters that must be focused while designing the device. The laminated structures serve as a magnetic core in the isolator because of the properties of MRE can be altered with changing of magnetic strength. The laminated structures consist of two steel blocks with 13 mm thickness, 28 layers of MRE sheets and 27 layers of steel plates. This laminated MRE isolator designed with 1 mm thickness of MRE and steel plate to enlarge distribution of magnetic flux. An electromagnetic coil extending around the coil bobbin with was provided to generate magnetic fields with 1400 number of coil turns. This number of coil turns was calculated based on the area designated coil bobbin, and the total electric resistance was 10.8 Ω.

The working principle of the laminated MRE isolator is as follows: the magnetic field generated by the coil can be controlled by the current from the external direct current power source, its shear modulus is determined by the strength of magnetic field, and the modulus determines the stiffness of the laminated MRE isolator. As the consequence, the natural frequency of the laminated MRE oscillator can be controlled by tuning the current in the coil, and then when the natural frequency of laminated MRE isolator matches the excitation frequency, the vibration can be suppressed significantly.

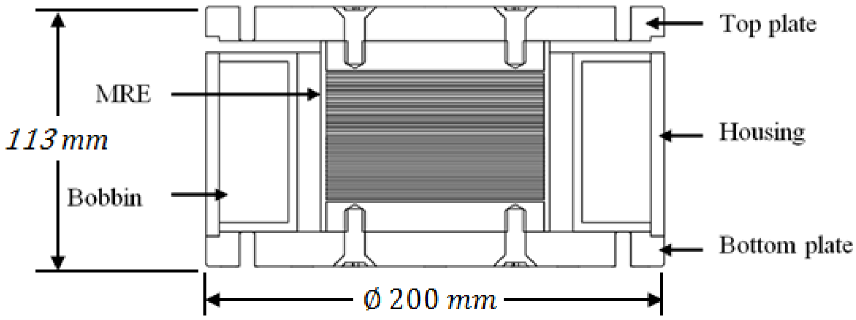

Figure 1. Cross section of the laminated MRE isolator

The materials that involved in fabricating the laminated MRE isolator were 1020 type of mild steel for magnetic materials, aluminium 6061-T6 for non-magnetic materials and AWG 18 coil. Details for each part of MRE isolator are shown in Table 1. The fabrication of laminated structures was done at Malaysian Rubber Board (MRB) experimental station. The others part in the laminated MRE isolators which are bobbin, housing, bottom and top plate as shown in Figure 2 was fabricated at the precision lab (MJIIT) using lathe machine and computer numerical control (CNC) machine.

Table 1. List of parts and materials for laminated MRE isolator

Part no	Part name	Type of material	Material	Type
1	Steel plate	Magnetic	Low carbon steel	1020
2	Top and bottom plate	Magnetic	Low carbon steel	1020
3	Steel block	Magnetic	Low carbon steel	1020
4	Wire coils	Non-magnetic	Copper wire	18SWG
5	Bobbin	Non-magnetic	Aluminium	6061-T6
6	Housing	Magnetic	Low carbon steel	1020

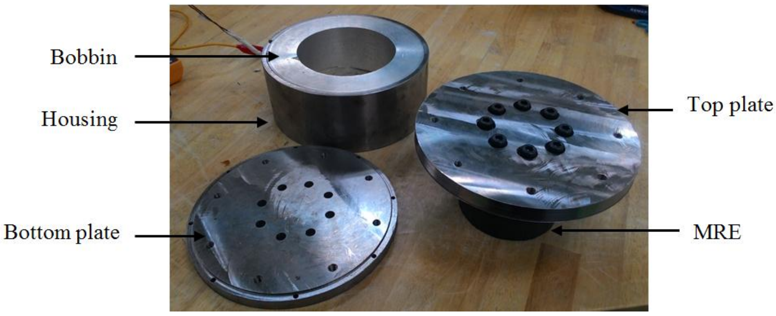

Figure 2. Main parts consist in a laminated MRE isolator

3. Experimental Testing

To observe the performances of laminated MRE isolator, a series of static compression test was conducted. The experiment was carried out using dynamic fatigue machine (Shimadzu Servopulser) equipped with a 20 kN load cell for a compression test. The experimental setup for compression test consisted of four main components; namely Shimadzu Fatigue Dynamic Test Machine, prototype, power supply and computer. The arrangement of the experimental test is shown in Figure 3. The laminated MRE isolator was attached to the testing machine. Then, the testing machine was connected to the data logger to record the result obtain from the compression test. The laminated MRE isolator was connected with a power supply with a capacity of 240 V and 24 A to generate a magnetic field to the magnetic coil of the isolator. The device is mounted on the load cell and compressed until 30% strain from the gap between the top plate and the bobbin. The test was performed without the magnetic field which is in “passive” state, and with magnetic fields exists which is in “active” state varies from

1 to 3 A. A series of tests, with static compression with 30% constant strain and energized with different applied currents from 1 to 3 A. Both stress and strain data can be directly obtained from the experimental result. The stiffness data was developed from the force and displacement data using mathematical equation.

Figure 3. Experimental setups for laminated MRE isolator

4. Result and Discussion

Figure 4 shows the stress measurement of laminated MRE isolator with 30% strain controlled for different applied currents, start with 0 until 3 A. As seen in the figure, the stress increased as applied current increased. The patterns of the graph are similar in such way that the stress was increased with the increased the percentage of strain for four different value of current applied. The stress value has increased from 0.9 to 1. 26 N/mm^2 as the applied current increased from 0 to 3 A. the increment of stress value, however, is not proportional with the increment of applied current. The different in values of stress measurement are becoming lesser as the applied current increases. But then still the stress measurement of laminated MRE isolator are affected by the applied currents, wherein general, the current plays a role in increased the performances of the semi-active device. It is clearly observed that laminated MRE isolator exhibit force increase with the increase of the applied current.

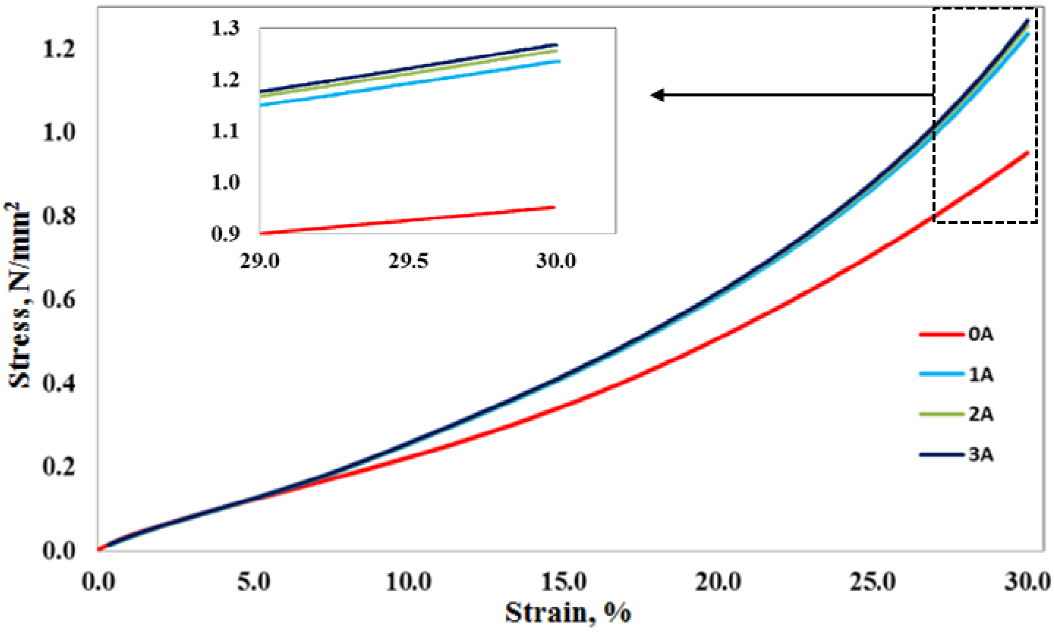

Figure 4. Force-Displacement graph of laminated MRE isolator

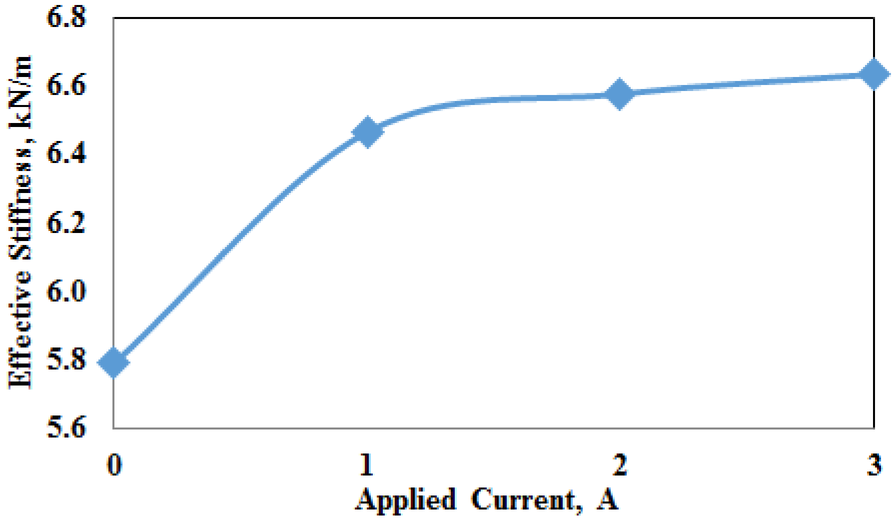

Figure 5. Effective stiffness of the laminated MRE isolator under various applied current

The effective stiffness for laminated MRE isolator during compression loading under applied magnetic field from 0 to 3 A are listed in Table 2. The effective stiffness increase for each applied current varies from 11.7 to 14.6%. From the increasing value of effective stiffness, it shows that the effective stiffness during compression loading was increased with the increased of applied current in the device.

Table 2. Effective stiffness of the laminated MRE isolator under various applied current

Current (A)	0A	1A	2A	3A
Effective stiffness (kN/m)	5.79	6.47	6.58	6.63
Increase (%)	-	11.7	13.6	14.6

5. Conclusion

This paper has delivered development of laminated MRE isolator utilizing MRE based NR material which provides adaptability to a different range of external excitations during a seismic event. The laminated MRE isolator was designed, fabricated and tested. The design of laminated MRE isolator was adapted from conventional laminated rubber bearing to offer high vertical loading capacity and low horizontal stiffness. Experimental investigations were conducted to examine the performances of laminated MRE isolator during compression loading with different magnetic field intensities. During compression loading, the laminated MRE isolator exhibits the field-dependent property where an increase in applied current leads to an increase in stress and effective stiffness. The experimental results demonstrate increasing in both stress and effective stiffness up to 14.56% under increasing the magnetic field intensities from 0 to 3 A. The study on the effect of magnetic field strength during compression loading further improve the adaptability of laminated MRE isolator to sustain the vertical excitation during an earthquake. So that, this laminated MRE isolator have the ability to change targeted isolation excitation range promptly and can sustain high vertical loading. Future work may focus on the experimental test for simultaneous vertical and horizontal and modelling for laminated MRE isolator.

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