Evaluation of Hybrid Viscoelastic Damper for Passive Energy Dissipation

S. S. Ghodsi, M. H. Mehrabi, Zainah Ibrahim, Meldi Suhatril

Abstract**—**This research examines the performance of a hybrid passive control device for enhancing the seismic response of steel frame structures. The device design comprises a damper which employs a viscoelastic material to control both shear and axial strain. In the design, energy is dissipated through the shear strain of a two-layer system of viscoelastic pads which are located between steel plates. In addition, viscoelastic blocks have been included on either side of the main shear damper which obtains compressive strains in the viscoelastic blocks. These dampers not only dissipate energy but also increase the stiffness of the steel frame structure, and the degree to which they increase the stiffness may be controlled by the size and shape. In this research, the cyclical behavior of the damper was examined both experimentally and numerically with finite element modeling. Cyclic loading results of the finite element modeling reveal fundamental characteristics of this hybrid viscoelastic damper. The results indicate that incorporating a damper of the design can significantly improve the seismic performance of steel frame structures.

Keywords**—**Cyclic loading, energy dissipation, hybrid damper, passive control system, viscoelastic damper.

I. Introduction

NOWADAYS, conventional structural seismic-resistant systems such as concentric braced frames (CBFs) and steel moment resisting frames (MRFs), are manufactured and designed for use in essential plastic deformations and in the creation of a global plastic mechanism for moderate to strong earthquakes [1]-[4]. This type of design philosophy has various positive advantages including both economical and less stress formation in structural members [3], [4]. Nevertheless, plastic deformations have certain negatives including residual drifts and economic setbacks. The cost of repair and demolition of the building are also high because of the complications which are related to straightening and repairing huge residential drifts [5].

Nowadays, structural systems which can achieve high performance are in much demand in modern societies. Therefore, there should be no damage resulting from small or moderate earthquakes and significantly less damage resulting from severe earthquakes, which can be repaired with no major loss to the operating of the building [6]. The expectation from performance-based seismic design is to concentrate and focus on modern energy dissipation systems for instance passive dampers [6]. Although the initial building designs of these systems will be expensive, they will result in decreased loss of life due to earthquake damage [6]. Passive control systems are displacement dependent devices which include friction dampers and yielding metal dampers or velocity dependent devices such as viscous fluid dampers or viscoelastic solid.

Viscous fluid dampers consist of a cylinder and a piston with orifices. The piston is stored in a cylinder which is filled up with liquid silicone or a similar oil [7]. During an earthquake, the movement of the structure results in the driving of the piston head through the fluid. The force-velocity relationship of the damper can either be linear or nonlinear as it greatly relies on the shape of the orifice. A viscous damping wall is yet another type of viscous fluid device which dissipates the energy. The energy is dissipated by dragging a plate through a ‘wall’ which has viscous fluid [8]. Usually, same amount of stiffness can be found in structures being augmented with viscous fluid dampers. This is because the devices do not possess any inherent stiffness when they reach a specific frequency range mostly involving the fundamental frequency of the structure.

Essentially, viscoelastic devices are comprised of a viscoelastic material pad sandwiched between steel plates. In viscoelastic material, energy is dissipated through huge shear strains. A little enhancement in structural stiffness due to the inherent storage stiffness of the viscoelastic material takes place because of the implementation application of viscoelastic dampers. The main advantage of viscoelastic dampers and viscous fluid are their ability to dissipate energy under every type and level of ground motion [7].

The basic purpose of this study is to investigate a hybrid viscoelastic damper (HVED) which uses both shear strain as well as compressive strain of rubber material for the purpose of energy dissipation. The fundamental features of the system will be discovered through the cyclic loading tests. Parametric studies will be carried out which demonstrate the usefulness and effectiveness of the damper system. The overall objective of this study is to investigate the idea of combining shear strain and compressive strain behavior of the rubber material for energy dissipation purpose.

II. Description of the Damper

The proposed damper is a passive control device. From a strategic point of view, the damper involves compressive strain and shear strain behaviour of viscoelastic material in parallel. Fig. 1 illustrates the proposed vibration control system consisting of a Brace, VED and viscoelastic block

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(VEB). VED comprises of a high damping rubber which is fixed between outer and inner steel plates and can be shear deformed. Two added rubber blocks are used on each side of the damper which are fixed and installed in the frame by use of chevron braces. When the frame undergoes deformation due to the lateral load, the VEBs and VED shear pads produce axial strain and viscous shear strain in reaction to the relative inter-story drift, resulting in energy dissipation. Moreover, rubber is not used in tension because of the micro cracking problems. Due to this very reason, the rubber blocks are more workable in compression Thus, only one side of the VEBs were attached. The lab test specimen is shown in Fig. 2.

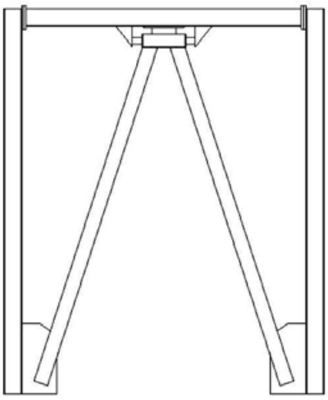

Fig. 1 The installation of the damper in frame

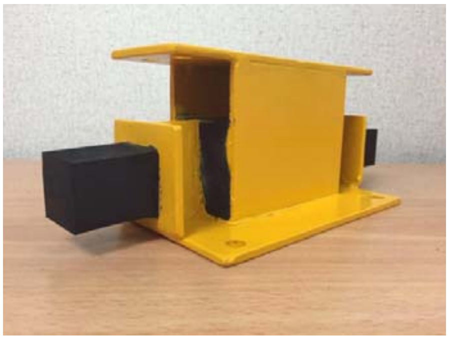

Fig. 2 The hybrid viscoleastic energy dissipation device

III. Experimental Study

Fig. 3 illustrates the HVED employed in the performance test of this paper. It is made up of two VE layers with each layer being 20 mm thick and vulcanised alternatively with three steel planes. The shear area of the VE layer is 5000 mm^2 and each steel plate has a thickness of 4 mm whereas the volume of each VEB is 36000 mm^3. An experimental test is conducted in a 1000 kN testing machine through displacement control mode for the verification and evaluation of the cyclic performance and behaviour of the damper. The test of the damper is carried out under a velocity of 3 mm/s with sinusoidal excitation by use of a fixed displacement amplitude. An acquisition system is used for recording the loading and displacement excitation data. The deformation of the damper is shown in Fig. 4.

Fig. 3 Sample 2 in testing apparatus

Fig. 4 Deformation of the damper

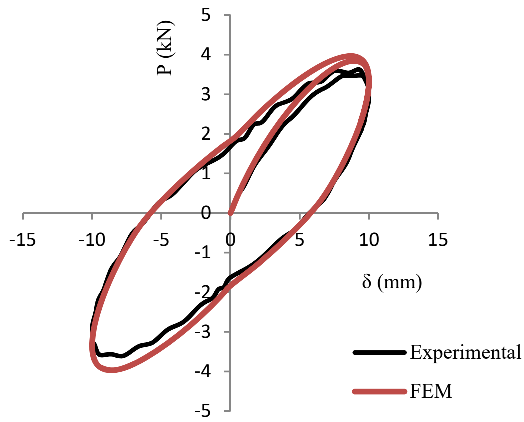

Fig. 5 Comparison of experimental and numerical results

To confirm the accuracy of the test data and to verify the results, nonlinear static analysis in finite element software, ABAQUS [9] was used. In this model, the rubber material is modelled using three-dimensional solid. Mehrabi et al. [10] presented the experimental results of uniaxial, shear and relaxation tests needed to model the behaviour of viscoelastic material in ABAQUS. Experimental and analytical hysteresis curves of the damper which are obtained from cyclic tests are illustrated in Fig. 5.

IV. Finite Element Method

The behavioral response of both rubber blocks and shear rubber pads influences the cyclic performance of the assembled damper. Therefore, proper consideration should be given to the most suitable specifications of the proposed damper. In this process, 5 three-dimensional finite element models of a damper are modeled in ABAQUS with the specifications listed in Table I. Fig. 6 represents the displacement history which is adopted in this parametric study.

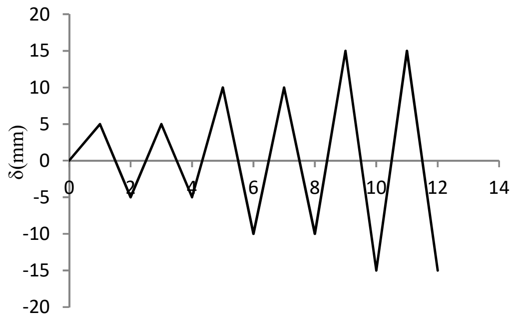

Fig. 6 Cyclic loading protocol

The samples response under cyclic loads is illustrated in Figs. 7 (a)-(d). The figures illustrate a load displacement hysteresis diagram and the energy dissipation-displacement relationship of all samples. The cyclic load displacement relationship for different rubber block volumes is illustrated in Fig. 7 (a). It demonstrates that the energy dissipated by the system increases substantiality through the increase in volume. It had been observed that an increase in stiffness is generated if there is a larger volume of the elements. Results of this form are expected due to an increase in the axial stiffness of the device. The effects of the area of the VEM pads are illustrated in Fig. 7 (c). With increases in the area, more energy is dissipated, and the corresponding force required for the same amount of frame displacement increases notably, indicating a higher level of stiffness. It is significant to note that the damper shows higher levels of stiffness and strength with greater imposed deformation.

TABLE I
SAMPLES' SPECIFICATION

Sample	VED Shear Area (mm^2)	VEB Volume (mm^3)	VED Thickness (mm)
S 1	5000	16000	20
S 2	5000	36000	20
S 3	5000	64000	20
S 4	2270	36000	20
S 5	8900	36000	20

Comparison between Figs. 7 (b) and (c) shows the deference in energy dissipation based on compression strain and shear strain of rubber material. Based on the results, the stiffness and energy dissipation of the damper may be controlled easily by the shape and proportioning of the device.

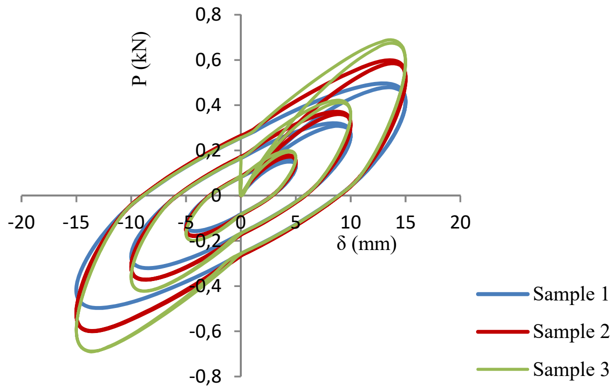

Fig. 7 (a) Cyclic behavior damper, effect of viscoelastic block volume

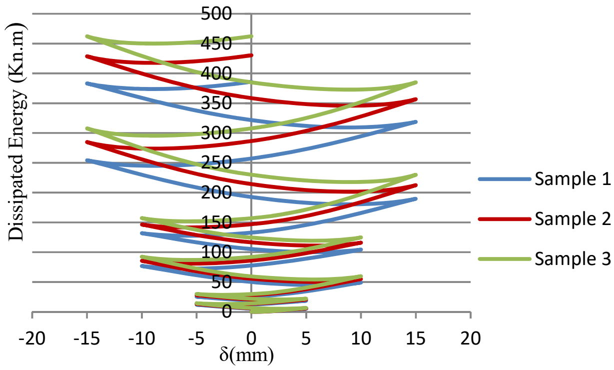

Fig. 7 (b) Cyclic behavior of damper, dissipated energy vs. Displacement

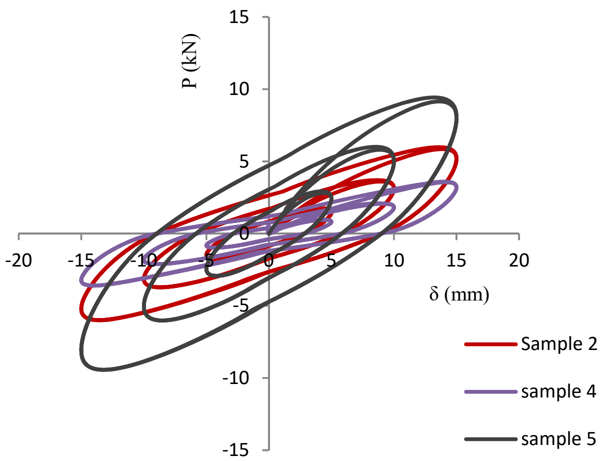

Fig. 7 (c) Cyclic behavior damper, effect of viscoelastic Shear area

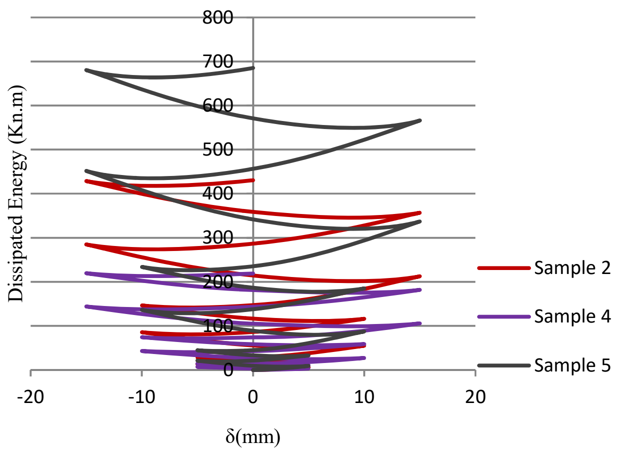

Fig. 7 (d) Cyclic behavior of damper, dissipated energy vs. Displacement

V. Conclusion

In this current study, HVED has introduced to protection structures under seismic loads. For construction of the devices, readily available materials which could be gathered in most structural steel fabrication plants were used. This could be revealed through cyclic loading tests demonstrating that the proposed system had a large energy dissipation capacity and stable hysteretic property. Also, a detailed finite element model of the device is constructed and analysed under cyclic forces using ABAQUS. The results of these analyses demonstrate that the device can be controlled easily due to many design parameters which can be selected and chosen for optimising its usage to dissipate energy for various structures.

Acknowledgment

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