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Use of silicon rubber as a viscoelastic material in dampers

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Abstract. One of the most extensively utilized structural control devices is the viscoelastic damper (VD), and significant study has gone into enhancing their efficiency in structures. The mechanical response of a VD supplied with silicone rubber as viscoelastic material (SRD) under various loading conditions is investigated in this research. A conventional VD is the SRD, which is made up of dual layers of rubber mounted between three steel plates. A total of two specimens were produced. To evaluate the influence of strain amplitude and excitation frequency on the mechanical characteristics of SRD, each damper was exposed to harmonic loading with different values. Hysteretic loops for each loading case were extracted, and the variations of several mechanical parameters with the variated loading conditions were inspected. The results indicate that SRD has a high energy dissipation capacity, and has stable performance under different working conditions. Finally, a proper simplified element model was created using SAP2000 software to evaluate the dissipation characteristics and control impact of the SRD in structures, and then a time history analysis was executed on multi storey structure. Due to the obvious dampers' extra stiffness and efficient damping property, the control impact of the SRD dampers on structural displacement is preferred and reflected on reducing the excessive displacement due to structure movement, according to data obtained.

1. Introduction

VDs are classified as an effective category of passive control devices, which enhance the dynamic properties of the structure to achieve vibration reduction via the hysteretic energy dissipation characteristics of viscoelastic material (VE). Compared with other control devices, VDs own the advantages of easy fabrication, long working life and low cost, which have been widely used in civil engineering, mechanical engineering, aerospace and other fields, as a vibration controller [1–4].
To examine the aspects that affect the mechanical properties of VDs, numerous experimental tests on their properties have been executed. The studies showed that this type of dampers has a durable energy dissipation property, and their performance is significantly sensitive to, excitation frequency, strain amplitude and temperature [5–10].

The mechanical characteristics of VDs have been shown to be substantially governed by properties of VE material, and the elements that influence the properties of VE materials are interconnected. Many studies have been performed to enhance VE energy dissipation feature [11–14]. However, it was noticed that silicon rubber (SR) has not gained enough attention. Hence, in this a study, a performance test has been implemented to evaluate SR as a viscoelastic material in reducing vibration induced in structures.

The dynamic characteristics of SRD are extensively examined and explored at various frequencies and strain amplitudes. Following that, SAP2000 software was used to construct a simplified model to define the behavior of the SRD. The simplified model was employed to model the SRD within a multi-story steel frame in order to examine its performance under a variety of earthquake records with different levels of intensity.

2. Experimental methodology

2.1. Test procedure
Mechanical behaviour experiments using the cyclic shear tests on the VD were done with varied loading frequencies and loading displacements to evaluate the mechanical behaviour and damping capabilities of the SRD. After the experiment is presented, the effects of loading frequency and loading displacement amplitude on the mechanical behaviour and damping characteristics of the damper are discussed.

In this research to design the VDs for the experiment, SAP2000 software was utilized to model the scaled down frame. The dampers were designed based on procedure prescribed in this reference [15] . Two samples of SRD were tested by dynamic testing machine. As shown in Figure 1(a), the damper sample comprises two silicon rubber layers sandwiched between three steel plates alternately. Each layer of SR is with a size of 100 × 75 × 6 mm^3. The performance test of the SRD has been performed using a 100 kN fatigue tester. The behaviour of samples was studied with a dynamic strain of 25, 50, 75, 100%, and the frequency were 0.1, 1.0, 3.0, and 5.0 Hz. The test overview is shown in Figure 1(b). The damper is exposed to ten sinusoidal excitations during each test.

The inner steel plate and two outer plates have mutually reversed motions during the experiment, and the VE material is subjected to standard shear deformation owing to the steel plate movements. The external loading's energy is converted to heat by shear deformation of the VE layers, which is subsequently released into the air.

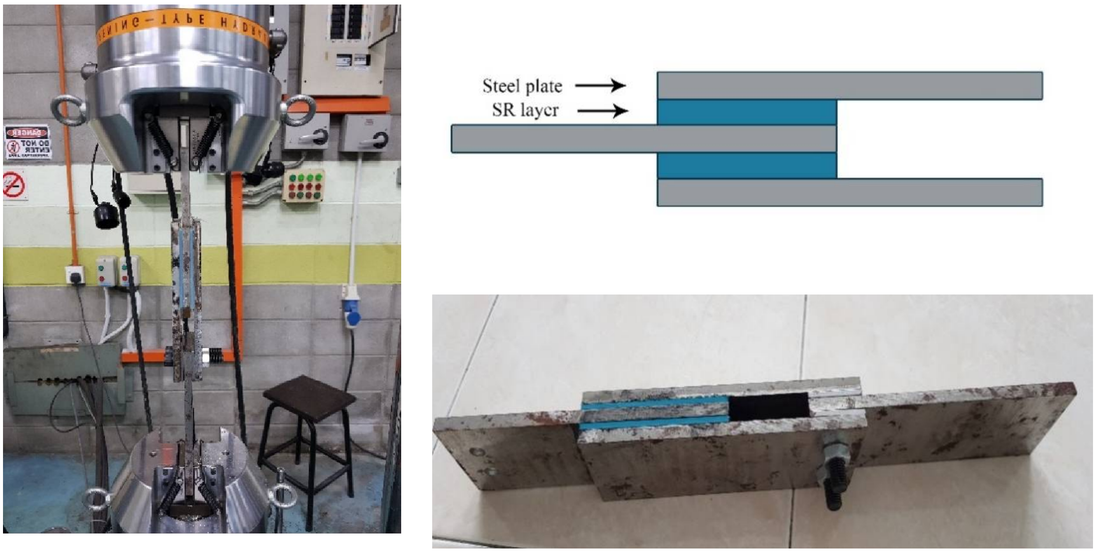


Figure 1. (a) test loading device; (b) SRD specimen.

2.2 Evaluation indices
The real energy lost or damped by the VDs is represented by the area contained by a hysteresis loop [16]. Figure 2 depicts a VD's hysteresis loop schematically. The form of the curve for a VD is quite similar to that of an ellipse, as depicted in Figure 2. For investigation of the mechanical properties of a VD with variety of loading frequencies and strain amplitudes, a stable hysteresis loop is chosen from the recorded data. The data collected for each loading condition is used to plot the SRD's hysteresis curves, as well as to estimate damper properties.

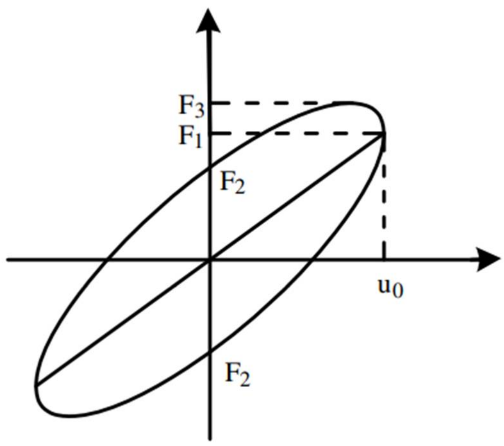


Figure 2. A typical hysteresis loop for viscoelastic materials.

The following evaluation indices were chosen to compare the effect on changing the loading conditions on overall behaviour of SRD and its mechanical characteristics. All of the potential indices were obtained using the experimental hysteretic curves' third cycle.

$$G_1 = \frac{F_1 h_v}{nAu_0} \quad (1)$$

$$\eta = \frac{F_2}{F_1} \quad (2)$$

$$G_2 = \eta G_1 \quad (3)$$

$$E_d = \frac{\pi n G_2 A u_0^2}{h} \quad (4)$$

$$K_e = \frac{nG_1 A}{h_v} = \frac{F_1}{u_0} \quad (5)$$

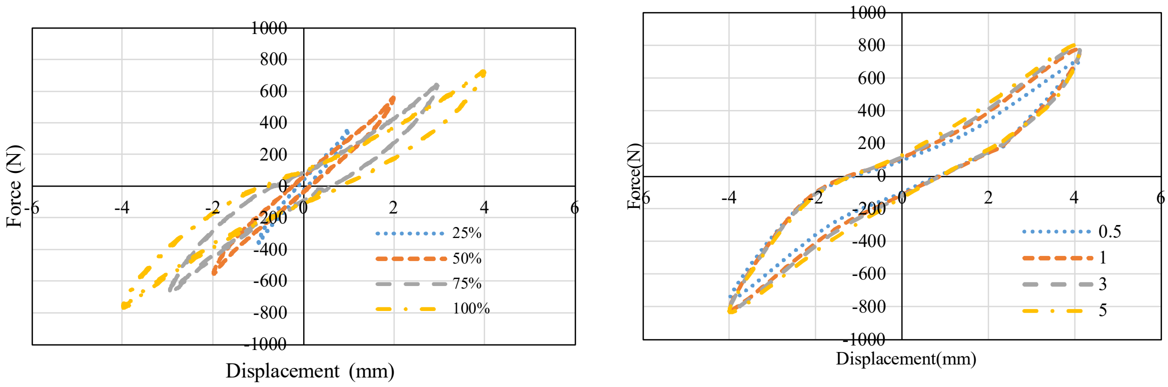
$$C_e = \frac{nG_2 A}{\omega} = \frac{F_2}{\omega u_0} \quad (6)$$

Where, “F_1”is the maximum shear force at maximum displacement “u_0”; “F_2” is shear force at zero displacement; h and A are the thickness and area of VE layer respectively; n is the number of VE layers in the VD; “G_1” is the storage modulus; η is the loss factor; “G_2”is the loss shear modulus; “Ke” is the equivalent stiffness; “Ce” is the equivalent damping; ω is the angular frequency loading which equal to “ 2πf ”. Ed is the energy dissipation.

3. Experimental results of damper

Figure 3 illustrates the experimental hysteretic curves for the force and displacement of the SRD under various loading parameters. The hysteresis loop at each case is approximately a full ellipse, indicating that the SRD can dissipate a lot of energy. Similarly, to the other types of VE materials, SR behaviour also affects by changing the displacement amplitude. As state previously, the domain of strains ranged from 25% to 100%, which is 1 mm, 2 mm, 3 mm and 4 mm as displacements values. As the amplitude increases the maximum force increases which means higher stiffness is attained and higher energy is dissipated. The damper shows non-linear response due to changing displacement amplitude, as shown in Figure 3(a).

The strong dependency of VE materials to changing loading frequencies is one of their primary limitations, making them unstable at both low and high excitation frequencies [17],[18]. Where the damper is still not active at low frequencies, reducing its effectiveness in mitigating vibrations. Higher frequencies, on the other hand, make the damper susceptible to unneeded deformation, which might lead to VE failure and the eventual destruction of damper. By changing the loading frequency, the SR material showed possibly lesser influence, as shown in Figure 3(b), eliminating the primary drawbacks mentioned previously. However, increasing the frequency still results in a higher response.



(a) (b)

Figure 3. Hysteresis curves of SRD change with different; (a) Strain amplitude and (b) Excitation frequency.

To show the effect of loading conditions on the overall behaviour of SRD, its mechanical characteristics under variety loading cases are obtained from the experimental tests, in accordance with Equations. (1)–(6). These properties are summarized in Table 1.

Table 1. Evaluation indices of the SRD response due to changing loading conditions.

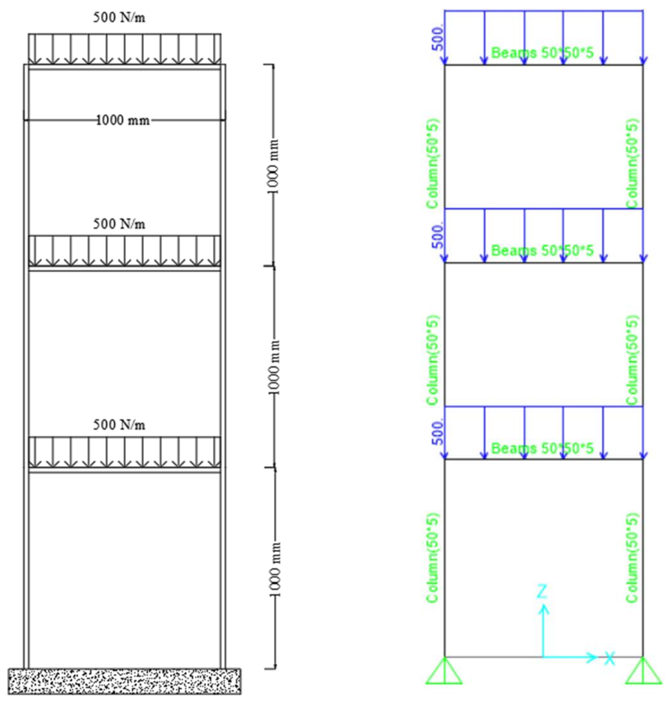
		G_1(MPa)	η	G_2(MPa)	E_d(N.mm)	K_e(N/mm)	C_e(N/mm)
Strain (%)	0.25	0.097	0.13	0.013	150.80	364	1.91
	0.5	0.073	0.13	0.009	439.82	273.5	2.79
	0.75	0.056	0.14	0.008	838.81	211	3.54
	1	0.049	0.15	0.008	1420.00	182.5	4.50
Frequency (Hz)	0.5	0.047	0.13	0.006	1193.81	176.25	7.56
	1	0.049	0.15	0.008	1420.00	182.5	4.50
	3	0.053	0.15	0.008	1482.83	197.5	1.57
	5	0.054	0.16	0.009	1633.63	201	1.04

Table 1 shows the variation of mechanical characteristics with the strain amplitude and excitation frequencies. Both storage shear modulus and shear loss modulus decrease when the shear strain increases from 25% to 100%. Whereas the other parameters increase as the strain amplitude increases. Despite the fact that the damping ratio decreases with increasing strain amplitudes, the results show that the SRD has a high energy dissipation capability.

The impact of loading frequency on the mechanical characteristics of SRD are the other loading parameter. The SRD was subjected to shear testing at four different loading frequencies, ranging from 0.5 to 5 Hz, with fixed shear strain of 100%. Table 1 also shows how different mechanical parameters of the SRD change with loading frequency. As the loading frequency increases the characteristic parameters tend to increase by increasing the loading frequency, except the damping coefficient which decrease by increasing loading frequency. Due to fact that the developed forces increase as the strain amplitude increases and the factors are directly proportional to the increase in stress induced in the damper. On the other hand the damping coefficient related inversely with loading frequency, that decreases it as the frequency increases.

4. Response of Structures equipped with SRDs

A numerical study on a scaled down two-dimensional three-story steel frame is done to analyse the efficiency of the SRD in minimizing the seismic response of building structures. The numerical study included proposition of a simplified model to represents the SRD in structural analysis software SAP2000, afterward a nonlinear time history analysis for bare frame and frame supplied with SRDs was performed. A two-dimensional single-bay three-story steel frame was scaled down to 1:3 using Buckingham's Pi Theorem [19]. The frame is 3 meters tall, with 1 meter story heights and a 1-meter span length. Figure 4 depicts the frame in more detail. Each floor's beams were subjected to an evenly distributed load of 500 N/m. The equivalent static analysis approach was used using SAP2000 software to design the frames in compliance with ASCE 7-10 [20].The columns are made of 50 mm steel plate, while the beams are made of 50 ×50 mm steel angle. For the design, A36 steel was used, which has a yield stress of 250 MPa and an ultimate stress of 460 MPa. The steel's Young modulus, E, was 200 GPa, and the Poisson's ratio, 0.3 [21]. Three earthquake records with different peak ground accelerations were used in the analysis inclusive of the El Centro, Northridge, and San Francisco earthquakes representing a high, moderate and low level of intensities, respectively.



(a) (b)

Figure 4. Details of the scaled down frame: (a) Details of frame and (b) SAP2000 model.

The scaled down bare frame was initially modelled in SAP2000 software and its essential vibration modes were predicted in order to develop the dampers utilized in the experiment test. The size of dampers has mostly been determined by the mentioned frame size; hence, the same damper features were utilized to simulate in SAP2000.

One damper was fastened to each floor. Figure 5 depicts the model of the frame as well as the dampers layout. A simplified link model was used in SAP2000 software to model the damper. The suggested model was used to reproduce the dynamic behaviour of the SRD in order to assess its correctness.

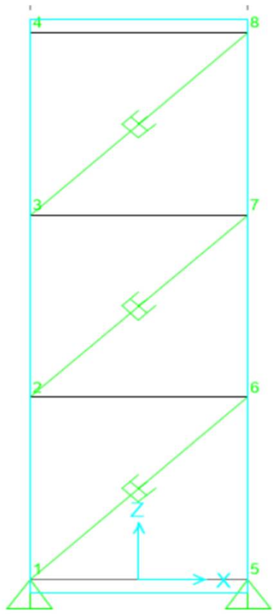


Figure 5. Configuration of SRDs within the frame model in SAP2000.

The damper was evaluated using sinusoidal excitations, and the results were compared to those obtained in the experiments. Figure 6 compares the results of the SAP2000 with the experimental test. It is obvious from the results that the model built in SAP2000 and the experimental test have a good matching.

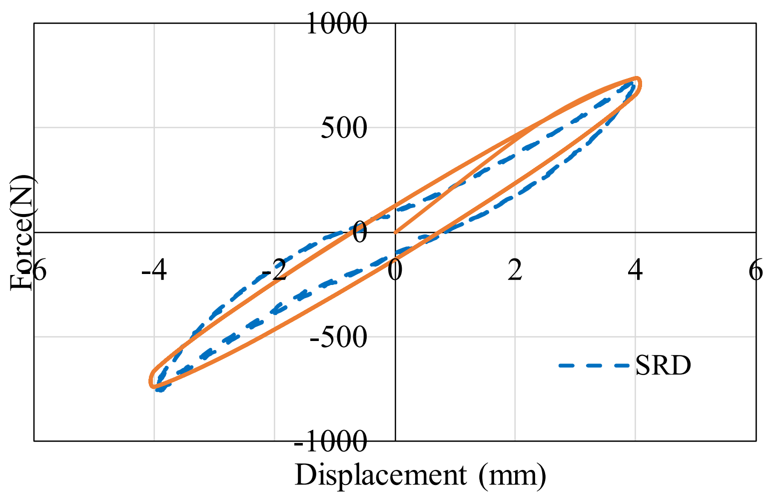


Figure 6. Assessment of responses obtained by SAP2000 and experimental test.

After validation of the damper model, the program was utilized to analysis the frame with and without the dampers. For comparison purpose, the displacements of third floor along with time for each

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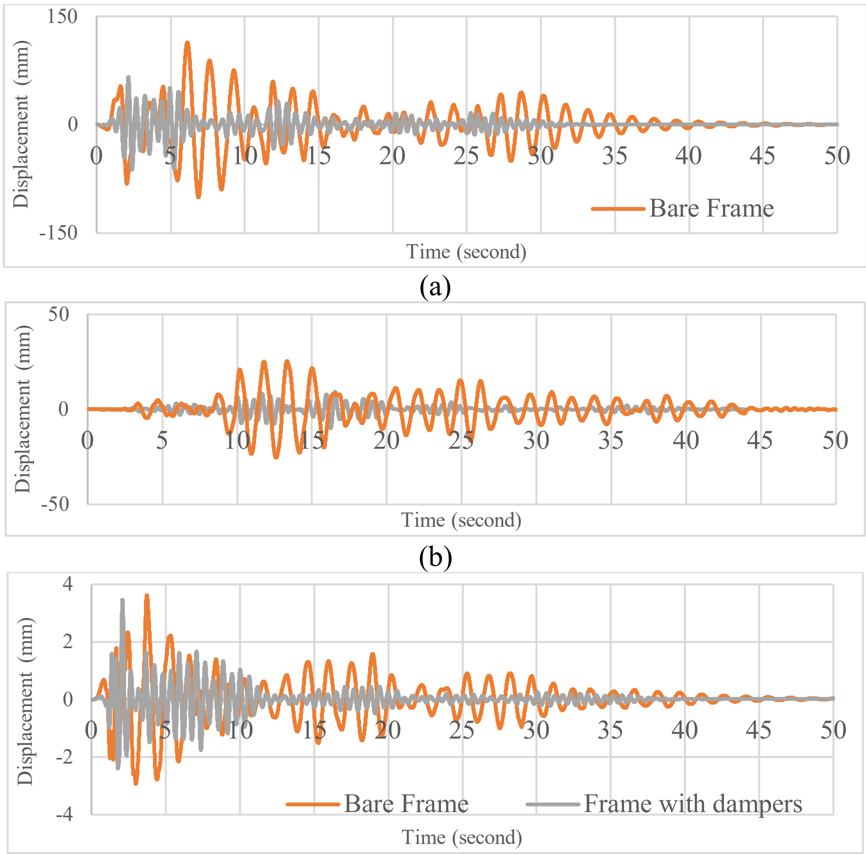
earthquake record were obtained and compared. Then, the responses of each frame for three records of each category were compared. Figure 7 depicts the time histories of the structure for the three earthquakes records. It is clearly shown that the installation of the SRD can effectively mitigate the responses of structure. Under the three levels of earthquake intensities, the SRD reduced the maximum displacements about 50% of that in the bare frame.



(c)

Figure 7. Time histories displacement calculated from the top story for under different earthquakes: (a) El Centro wave; (b) Northridge SN wave and (c) San Francisco wave.

5. Conclusion

The energy dissipation capability of a VD is derived from the intrinsic damping of the VE. The primary goal of this work was to investigate the energy dissipation capabilities of SR as a VE. A damper supplied with SR bounded to steel plates was tested across a variety of frequencies and strain amplitudes to fulfil the study goal.

The hysteresis curves of the SRD are rather full, indicating that this damper has a good energy dissipation capacity; displacement amplitude has a high influence on the dynamic characteristics of the SR damper, whereas excitation frequency has a less impact on these parameters. Under changing loading situations, the mechanical characteristics of the SR matrix VE damper are very constant.

SRD's performance and energy dissipation capacity are generally constant, despite its small loss factor. As a result, the created SRD is suited for shock absorption and can adapt to the variety loading conditions.

The nonlinear time history analysis showed the efficiency of SRDs in mitigating earthquakes. Under variety of earthquake records, frames supplied with SRDs showed a good resistance against ground vibrations

6. References

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