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# An experimental study on the dynamic shear properties of conjugated isolation systems

Gia Toai Truong[1)], Seung Jae Lee[2)], Kyoung-Kyu Choi[3)], Baek Seon Woo[4)] and *Changsoo Kim[3)]

*[1), 3), 4)] Department of Architecture, Seoul National University of Science and Technology, Seoul 01811, Korea*
*[2)] School of Architecture, Soongsil University, Seoul 06978, Korea*

*[3)] changsookim@seoultech.ac.kr*

## ABSTRACT

In this research, full-scale conjugated isolation systems were fabricated from separate rubber and wire isolators to investigate their dynamic properties. The testing program includes compressive stress dependence test and shear strain dependence test. Since the dynamic shear properties in X-direction was examined independently of Y-direction, three specimens in X-direction and three specimens in Y-direction were made and tested for each type of tests. Also, at each compressive stress or shear strain level, the cyclic loading with three cycles was conducted. The effects of compressive stress and shear strain levels on the dissipated energy, damping ratio, shear stiffness, and shear modulus of the isolation systems were investigated and discussed.

## 1. INTRODUCTION

In recent years, seismic isolation devices have gained popularity as one of aseismic design concepts to diminish the seismic force transmitted to the superstructures (or facilities such as electrical and mechanical devices) while carrying vertical loads. Normally, these seismic isolation devices were assembled between superstructures (or facilities) and ground. As a result, the presence of the seismic isolation devices may decouple the superstructures from the ground effects and thus would partially help to elongate the natural period of the superstructures [1].

Numerous experimental studies have been performed to investigate the effectiveness of seismic isolation devices on seismic performance of superstructures. Nonetheless, fundamental studies of seismic effect on the superstructures like electrical

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[1)] Postdoctoral Research Professor
[2)] PhD Student
[3)] Professor
[4)] Undergraduate Student

and mechanical facilities were still limited. Moreover, it is well recognized that the mechanical properties of the isolation devices affect significantly the seismic performance of an isolation system and a superstructure, it is necessary to determine and design their characteristics cautiously.

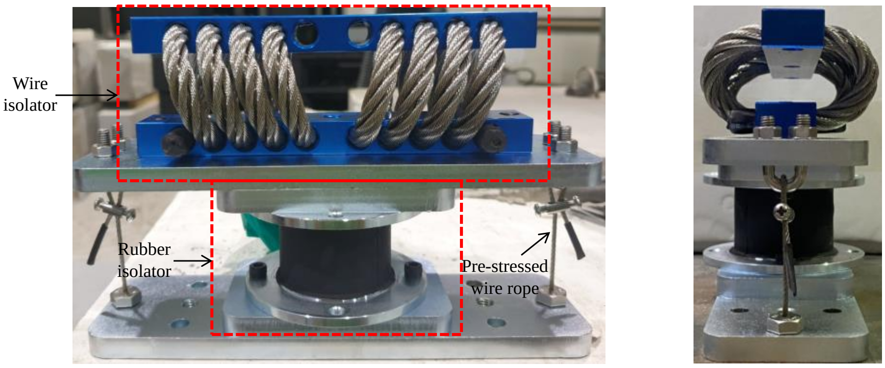
In reality, various isolator systems have been developed and carried out world-widely for the seismic protection of the superstructures such as elastomeric isolator systems, which are made up with alternating layers of natural, synthetic, or rubber and steel plates; lead-rubber isolators, which are modified from low-damping rubber isolators by adding a press-fit lead-plug into a central hole in the bearing; and sliding isolation system, which composes of a bearing resting on a sliding interface. Moreover, many device tests have been executed to investigate many mechanical and dynamic characteristics of isolation systems such as shear strain dependence, temperature dependence, frequency dependence, vertical loading force dependence, aging effect, and ultimate performance.

This research introduced a novel isolation system using combined rubber and wire isolators to use for the non-structural components like electrical and mechanical facilities subjected to earthquake loading. The dynamic properties of this isolation system were investigated through the device tests comprising of compressive stress dependence and shear strain dependence with full-scale test specimens following ISO 22762-1 [3].

## 2. TESTING PROGRAM

### *2.1 Test specimen*

In this research, as shown in Fig. 1, a combined isolation system, comprising a high hysteresis laminated rubber isolator and a wire isolator, was developed for seismic isolation of non-structural components. In addition, at the borders of the rubber isolator, two pre-stressed wire ropes were installed with a tensile stress of 6 MPa to induce a pre-compressive stress on the rubber isolator. Table 1 summarizes in details the characteristics of rubber and wire isolators employed in the present study.




Front view Side view

Fig. 1 Photo of isolation system used in this study

Table 1 Detailed characteristics of an isolation system used in this study

| Type | Features | Mechanical properties |
|---|---|---|
| Laminated rubber isolator | - Diameter of rubber: 50 mm<br>- Rubber thickness: 2.5 mm<br>- Number of rubber sheets: 8<br>- Steel plate thickness: 2 mm<br>- Number of steel sheets: 7 | - Shear modulus of rubber: 0.4 MPa<br>- Bulk modulus of rubber: 2000 MPa<br>- Horizontal stiffness ( $k_h$ ): 540.0 N/mm<br>- Vertical stiffness ( $k_v$ ): 10426.2 N/mm |
| Wire isolator | - Wire diameter: 9.5 mm<br>- Number of loops: 8<br>- Width of a loop: 80 mm<br>- Length of retainer: 170 mm | - Wire rope yield strength: 205 MPa<br>- Wire rope ultimate tensile strength: 520 MPa<br>- Horizontal stiffness ( $k_h$ ): 93.4 N/mm<br>- Vertical stiffness ( $k_v$ ): 2329.8 N/mm |

### *2.2 Test setup*

The setup for device tests of the isolator specimens is presented in Fig. 2. From the figure, the test specimens were vertically (compression) and horizontally (shear) loaded using a hydraulic jack (loading capacity of 50 kN) and lateral actuator (loading capacity of 100 kN), respectively. The compression and shear forces were acquired via two load cells A and B as shown in Fig. 2. The top of the test specimen was linked to load cell A through a steel plate to assure the uniform load applied to the isolator system, and the bottom of the test specimen was supported by a steel frame, which was laid on a rolling system allowing the test specimen could easily move under lateral load.

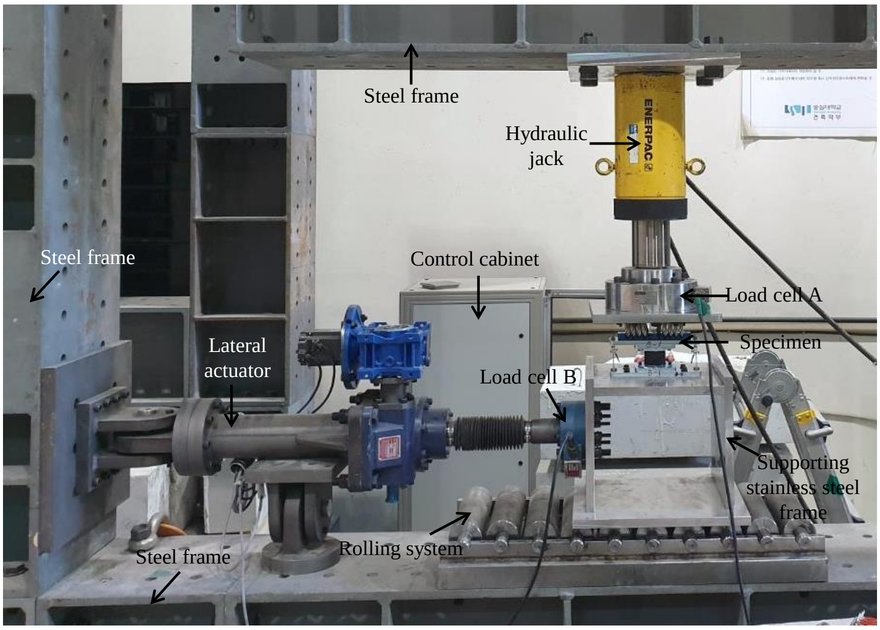
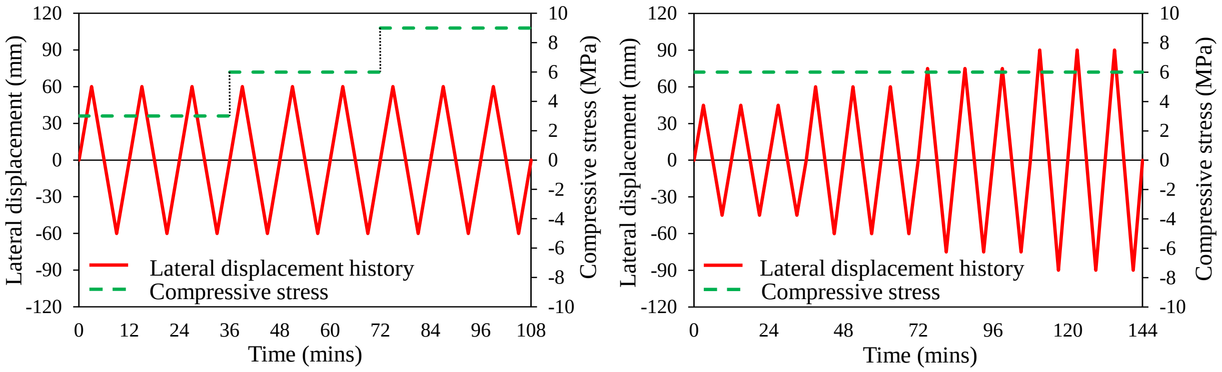



Fig. 2 Setup for device tests

Fig. 3 describes the cyclic loading histories for compressive stress dependence and shear strain dependence tests. For compressive dependence test (Fig. 3(a)), the specimen was subjected to a constant lateral displacement of $\Delta_0$ (= 60mm), and the compressive stress increased in order of $0.5\sigma_0$ (= 3MPa), $\sigma_0$ (= 6MPa), $1.5\sigma_0$ (= 9MPa). For shear strain dependence test (Fig. 3(b)), the specimen was subjected to a constant compressive stress of $\sigma_0$ (= 6MPa), and the amplitude of the lateral displacement increased in order of $0.75\Delta_0$ (= 45 mm), $\Delta_0$ (= 60 mm), $1.25\Delta_0$ (= 75 mm), and $1.5\Delta_0$ (= 90 mm). For each value of the compressive stress or lateral displacement, the number of cycles is three.



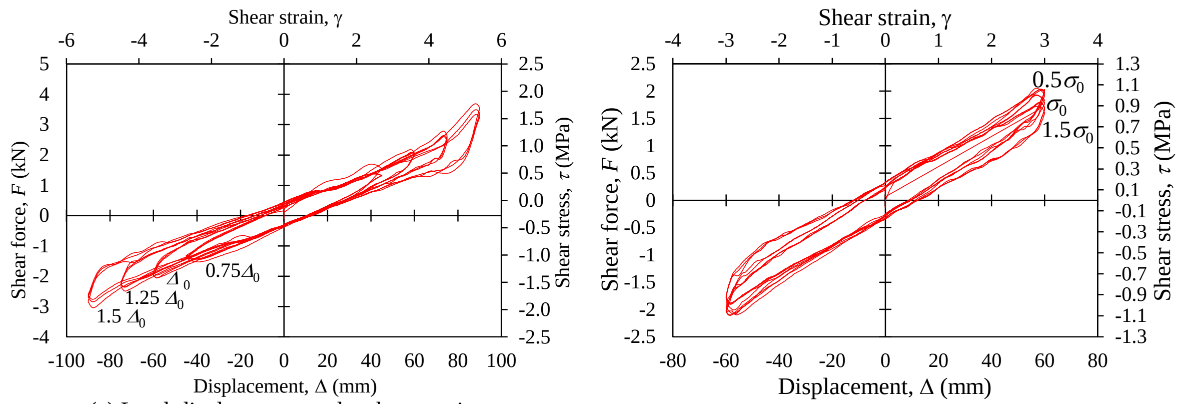

(a) Compressive stress dependence test

(b) Shear strain dependence test

Fig. 3 Loading history

## 3. TEST RESULTS

Figure 4 presents the load-displacement (or stress-strain) responses for all cycles of the test specimens in the X-direction under compressive stress dependence and shear strain dependence tests.




(a) Load-displacement under shear strain dependence test in X-direction

(b) Load-displacement under compressive stress dependence test in X-direction

Fig. 4 Load-displacement response of test specimens

In Fig. 4(a), at each lateral displacement stage (or strain stage), the stress-strain relationships at the first, second, and third cycle of each strain stage did not show considerable difference. Similar observations could be found in the case of compressive stress dependence test (Fig. 4(b)). In the Y-direction, the test specimens exhibited similar characteristics of stress-strain responses.

For comparison, dynamic shear properties of the isolation system were calculated (see Fig. 5). In shear strain dependence test, the test results showed that with the increase of the shear strain in both X- and Y-directions, the energy dissipation of the isolation system increased while the damping ratio showed a reduction trend. In the cases of shear modulus and shear stiffness, the isolation system produced almost constant values in X-direction but a reduction trend was found in Y-direction. In compressive stress dependence test, with the increase of compressive stress, in both X- and Y-directions, the energy dissipation and damping ratio of the isolation system showed a trend to increase while the shear modulus and shear stiffness exhibited a slight decrease.

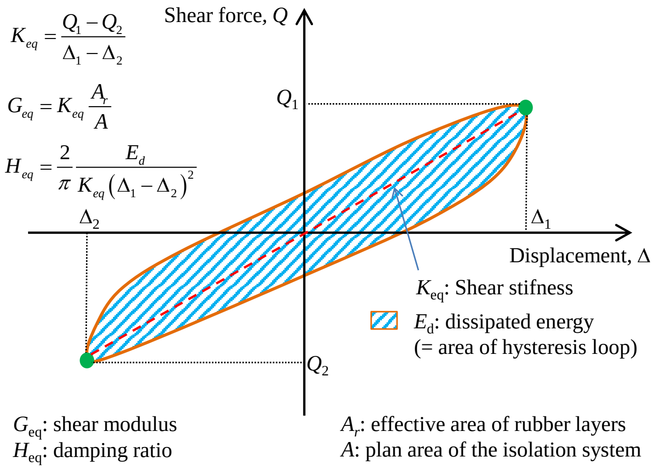



Fig. 5 Definition of shear properties of isolation system

## 4. CONCLUSIONS

In this research, the dynamic shear properties of a novel isolation system were examined through the testing program including compressive stress dependence test and shear strain dependence test with full-scale test specimens. Three cycles was conducted at each level of compressive stress or shear strain. In the test, the examination of dynamic shear properties in X-direction was independent of Y-direction. The obtained test results indicated that the increase of shear strain increased energy dissipation but reduced the damping ratio, whereas the increase of compressive stress increased damping ratio.

## ACKNOWLEDGEMENT

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