

## **INFLUENCE OF ASPECT RATIO AND BONDING PERCENTAGE ON DAMPING BEHAVIOR OF ELASTOMERIC BASE ISOLATORS UNDER BIDIRECTIONAL LOADING**

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### **ABSTRACT**

The damping behavior of square Scrap Tire Rubber Pad (STRP) base isolators with different aspect ratios and bonding levels is investigated in this study when cyclic lateral stress is applied at various angles. Five different isolator sizes—24mm×24mm×24mm to 72mm×72mm×24mm—and bonding ratios—0% (unbonded) to 100% (completely bonded)—are included in the study. Scrap tire rubber pads can use as sustainable, economic base isolators that minimize environmental waste and improve seismic protection. PB-STRP models damping effect are calculated using MSC Marc-Mentat FEA for varied loading directions. Under 5.0 MPa static vertical pressure, variable lateral loading angles, and 250 percent shear strain. Aspect ratio of 3 has shown highest effective damping and AR-1 lowest. Initially it increases with increasing of ratio but at AR-2.5 interrupt that pattern. Uneven damping might affect performance. However, insufficient damping reduces energy dissipation, increasing displacements and base shear demands, compromising stability.

**Keywords:** *Effective Damping, PB-STRP, Aspect Ratio, Base Isolator, FEA*

## **1. INTRODUCTION**

In developing countries, however, seismic design approaches and options are often overlooked during the construction and development of low-to-medium-rise buildings due to financial conditions. Many structures are therefore vulnerable to seismic hazards, as such natural disasters cause considerable infrastructural harm and casualties. Several anti-seismic notions and design codes and specifications have established creative ideas and approaches to minimise seismic harm and enhance a structure's resistance to earthquakes. Among the techniques, one of the most widely used is installing base isolators between the superstructure and foundation, such as steel-reinforced elastomeric isolators, which reduces the structure's seismic demand during an earthquake availability. Indeed, (Kelly, 2002) identifies that both the excessive cost and difficult manufacturing process of SREIs make it unfeasible for high retrofit or no-commercial construction, specifically in developing countries, as noted by (Pan et al., 2005).

In conclusion, recent research and development have developed creative and affordable seismic isolation technologies, which are ideal for poor nations. The use of locally available or recycled materials, reduction of production costs and energy use, as well as simplified design and installation, are the essential goals of contemporary development. To address these problems, scientists have invented some of the most affordable simple isolators, namely, polyester fibre-reinforced isolators (Tan et al., 2014), rubber-soil mixes (Tsang et al., 2012) scrap tire pad isolators (Turer & Özden, 2007) friction sliding isolators (Xiao et al., 2003) and fibre-reinforced elastomeric isolators (FREIs) (Kelly, 1999). Scrap tire rubber pad isolators, which are produced from old automobile tires, are an economical and environmentally sustainable form of seismic isolation. Due to the simplicity of the installation and the preparation of STRP isolator, they appear to be well-suited for poor and underdeveloped countries (Mishra, 2012). This not only diminishes production expenses but also reduces the impact on the environment of the 1.5 billion tires that are generated each year throughout the world. According to (Mashiri et al, 2015), they claim that STRP isolates are a cost-effective approach to limit earthquakes and reduce environmental pollution. First, experimental research and numerical simulation were able to assess square pads from scrap tires in terms of their ability to work in compression. (Turer & Özden, 2007) report that unbonded STP can hold a load of 8.5 MPa until the steel chord fails. In the same article, they mention that scrap tires have a shear modulus of 1 MPa and a damping ratio of 18-22%. Moreover, (Hossain et al., 2024) explored the force-displacement relationship and the lateral performance of square shaped STRP isolators subsequent to earlier studies made on unbonded, bonded and partially bonded STRP isolators. In this experiment, we attempt to determine the effective damping of unbonded, partially bonded, and fully bonded isolators with sizes ranging from 24 mm x 24 mm x 24 mm to 72 mm x 72 mm x 24 mm square based base isolators for six distinct loading directions ranging from 0° to 75°, separated by 15°. This study examined the stability of the STRP isolators with regard to different aspect ratios and determined the optimal design configuration.

## **2. METHODOLOGY**

In addition to finite element analysis, this endeavour involves material modelling, model development, and model verification. The flowing chapter provides a detailed explanation of each methodological component.

### **2.1 Modelling of Scrap Tire Rubber Pad Base Isolator**

A vehicle tire is formed by vulcanizing rubber with steel cable, much like a steel-reinforced elastomeric isolator. Figure 1 illustrates the process of turning discarded tires into rubber pads (HK, 2012). The STRP isolator was made by adhering individual 12 mm rubber pads in a layered fashion. The features of the steel cable and scrap tire used in STRP isolators, which are made from Bridgestone 385/65R22.5, are detailed in Table 1. Aspect ratio details with their bonded component are displayed in Table 3. Rubber modelling uses the Mooney-Rivlin model to accurately describe rubber's nonlinear elastic behaviour. (Mishra, 2012) used uniaxial testing to estimate the hyper-elastic

material constants for the three-term Mooney-Rivlin energy function. Table 2 lists the rubber material constants. The ratio of length to height is the primary concept of aspect ratio.

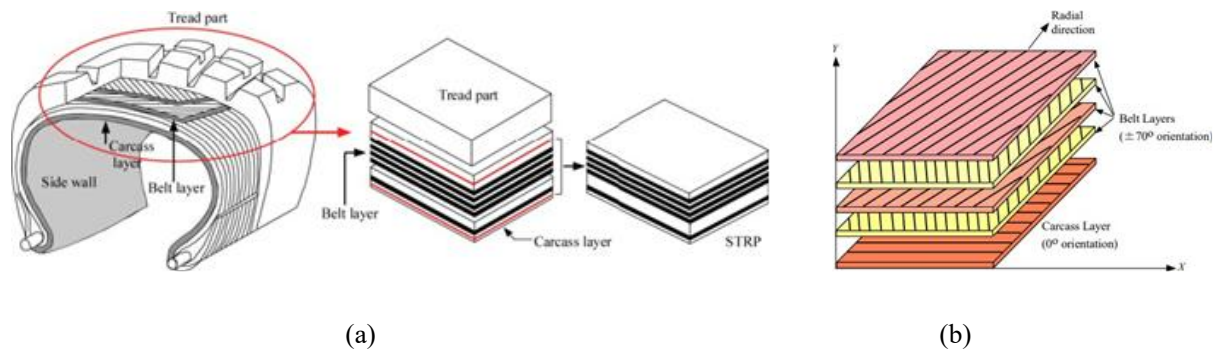


Figure 1: STRP isolator: (a) Fabrication of STRP specimen; (b) Arrangement of steel reinforcing cords

Table 1: Properties of reinforcing steel cord in a STRP isolator (Zisan & Igarashi, 2021) (Hossain et al., 2024)

| Layer   | Poisson's ratio, $\nu$ | No. of filament | Filament dia (mm) | Steel cord area ( $\text{mm}^2$ ) | Angle          | Equivalent Thickness $tf$ (mm) | Yield strength (GPa) | Modulus of elasticity $E$ , (GPa) |
|---------|------------------------|-----------------|-------------------|-----------------------------------|----------------|--------------------------------|----------------------|-----------------------------------|
| Carcass | 0.3                    | 5               | 0.2               | 0.44                              | $0^\circ$      | 0.40                           | 2800                 | 200                               |
| Belt    | 0.3                    | 14              | 0.4               | 0.63                              | $\pm 70^\circ$ | 0.40                           | 2800                 | 200                               |

Table 2: Mooney-Rivlin constants (Mishra, 2012)

| $C_{10}$ | $C_{01}$ | $C_{11}$ |
|----------|----------|----------|
| 0.40     | 1.22315  | 0.18759  |

Table 3: Bonded portion according to Aspect Ratio

| Model    | Aspect Ratio | Dimensions               | Bonded Portion (%) | Bonded Area        |
|----------|--------------|--------------------------|--------------------|--------------------|
| STRP-0   | 1.0          | $24 \times 24 \times 24$ | 0                  | $0 \times 0$       |
| STRP-25  |              |                          | 25                 | $12 \times 12$     |
| STRP-50  |              |                          | 50                 | $17 \times 17$     |
| STRP-75  |              |                          | 75                 | $21 \times 21$     |
| STRP-100 |              |                          | 100                | $24 \times 24$     |
| STRP-0   | 1.5          | $36 \times 36 \times 24$ | 0                  | $0 \times 0$       |
| STRP-25  |              |                          | 25                 | $18 \times 18$     |
| STRP-50  |              |                          | 50                 | $25.5 \times 25.5$ |
| STRP-75  |              |                          | 75                 | $31.2 \times 31.2$ |
| STRP-100 |              |                          | 100                | $36 \times 36$     |
| STRP-0   | 2.0          | $48 \times 48 \times 24$ | 0                  | $0 \times 0$       |
| STRP-25  |              |                          | 25                 | $24 \times 24$     |
| STRP-50  |              |                          | 50                 | $34 \times 34$     |
| STRP-75  |              |                          | 75                 | $41.6 \times 41.6$ |
| STRP-100 |              |                          | 100                | $48 \times 48$     |
| STRP-0   | 2.5          | $60 \times 60 \times 24$ | 0                  | $0 \times 0$       |
| STRP-25  |              |                          | 25                 | $30 \times 30$     |
| STRP-50  |              |                          | 50                 | $42.5 \times 42.5$ |
| STRP-75  |              |                          | 75                 | $0 \times 0$       |
| STRP-100 |              |                          | 100                | $60 \times 60$     |

|          |     |                          |     |                |
|----------|-----|--------------------------|-----|----------------|
| STRP-0   |     |                          | 0   | $0 \times 0$   |
| STRP-25  |     |                          | 25  | $36 \times 36$ |
| STRP-50  | 3.0 | $72 \times 72 \times 24$ | 50  | $51 \times 51$ |
| STRP-75  |     |                          | 75  | $62 \times 62$ |
| STRP-100 |     |                          | 100 | $72 \times 72$ |

## 2.2 Developing Finite Element (FE) Models

The STRP isolator is modelled using finite elements using Marc-Mentat software. An isoperimetric hexahedral element of the Herrmann type is used to model rubber material. This element is preferred for contact analysis and simulating massive deformations when compared to higher-order elements. The steel strands that support the rubber composite are imitated by a hollow isoperimetric rebar piece. Figure 3 (a) shows the sequential arrangement of the steel cord layers, also known as the carcass and belts 1 through 4. The rebar components put into the corresponding solid host components demonstrate the rubber matrix materials. L1 and L2 are the names of two 12 mm rubber-steel composites, respectively. A 24 mm STRP composite is created by geometrically positioning and overlaying L2 over L1. A bonded link models the interaction between L1 and L2. Two supplementary components with suitable dimensions are incorporated at the upper and lower faces of the isolator to simulate partial bonding between the STRP isolator and the surfaces of structural elements. They are referred to as "Bonded-Top" and "Bonded-Bottom" which shows in Figure 2. Rigid planes are employed to represent these contact surfaces. Figures 3(a) and 3(b) illustrate the finite element models of steel chords and STRP isolators, respectively, utilising a fine mesh. A static axial load of 5 MPa is applied to the top surface of each model. Figure 3(a) presents a comprehensive finite element model that incorporates all boundary conditions. Figure 3(d) demonstrates that the cyclic lateral displacement comprises six cycles, corresponding to shear displacements of 25%, 50%, 100%, 150%, 200%, and 250%. The lateral displacement is decomposed into two components according to its orientation and subsequently applied in two orthogonal directions of the isolator. Regarding the orthogonal direction, these components are aligned from 0° to 75° in increments of 15°. The primary objective of this study is to determine effective damping in relation to aspect ratio. The interaction between rubber elements and bonded sections, along with that between building components and bonded parts, is considered to be adhesive. In contrast, the connection between the unbonded portion of the isolator and building components is intended to be a mechanical contact. A friction coefficient of 0.8 is utilised for touch connections.

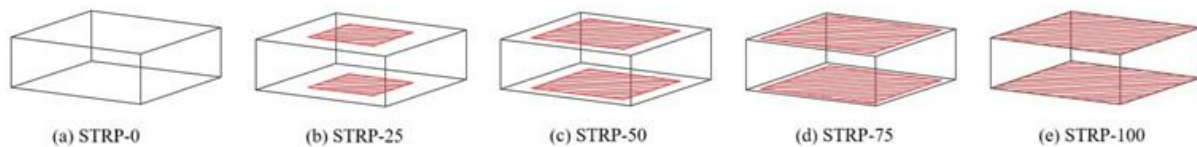


Figure 2: Bonded portion of STRP: (a) STRP-0; (b) STRP-50; (c) STRP-100

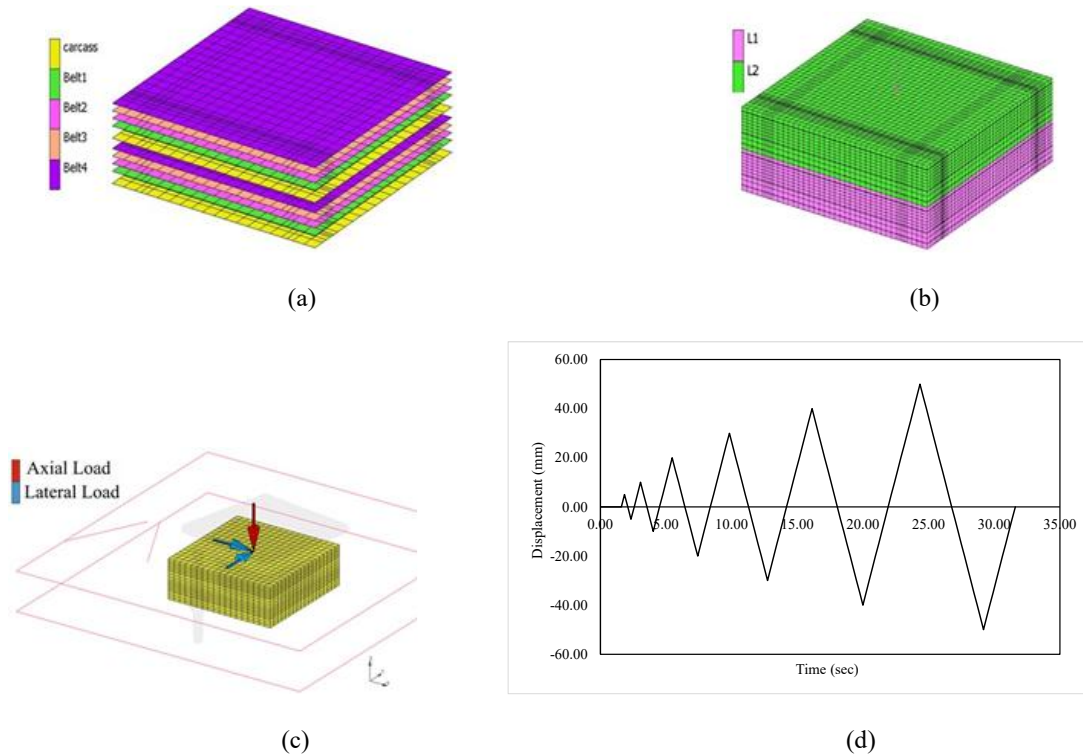


Figure 3: FE modelling of STRP : (a) Position of the embedded rebar components; (b) FE model mesh generation; (c) boundary conditions; (d) Lateral loading pattern

### 3. FINITE MODEL VERIFICATION

This section compares two models; our model and the reference model (Hossain et al., 2024) based on aspect ratios and loading conditions. Aspect ratio slopes fluctuation are compared for 0-degree loading angles. Slope at different Aspect Ratios. First, in Figure 4 we compared the slope of our model and the reference model when Aspect Ratio varies. The reference model's slope is always constant and negative as shown: Our model slope values indicate negative slope pattern for all a: Both the models are the almost same slopes; this indicate that our model is declining just as in the reference model. Initially, damping is increased with their % shear displacement and reached highest at 50% shear displacement but then it is started to drop. First, the isolator has been made it easier for the superstructure to stabilize quickly. However, the loosening of the isolator pads has been reduced the damping efficiency if the shear displacement has surpassed around 50% of its design capacity. The current test models and Mishra's experimental investigation both have showed a similar response pattern (Mishra, 2012). The verification findings have been shown that our model performs similarly to (Hossain et al., 2024)'s reference model too. Both models exhibit negative slopes at various aspect ratios and similar STRP-0 variation across different loading angles. This demonstrates our model's reliability and consistency relative to the reference model.

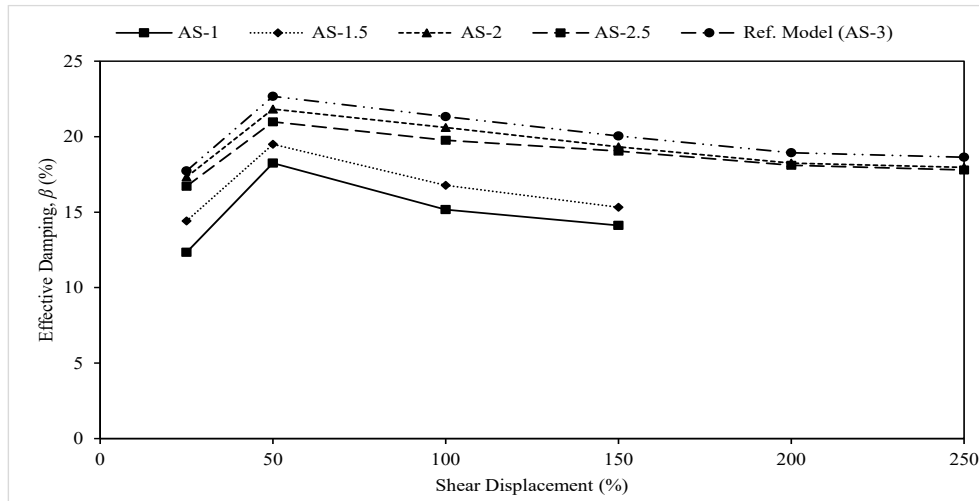


Figure 4: Validation of the FE model against the reference model

## 4. RESULTS AND DISCUSSIONS

### 4.1 Force-displacement Relationship

The figure 5 to 7 depicts the cyclic lateral load response of STRP isolators with varying bond percentages under shear displacements from 25% to 250% where Figure 5 (a) shows Aspect-1 at Y Axis hysteresis curve for 45° Loading; and (b) shows Aspect-1.5 at X Axis hysteresis curve for 45° Loading. Figure 6 (a) shows Aspect-2 at X Axis hysteresis curve for 45° Loading; and (b) shows Aspect-2 at Y Axis hysteresis curve for 45° Loading. Figure 7 (a) shows Aspect-2.5 at X Axis hysteresis curve for 45° Loading; and (b) shows Aspect-3 at Y Axis hysteresis curve for 60° Loading. Though 48mm x 48mm x 24mm, 60mm x 60mm x 24mm and 72mm x 72mm x 72mm isolators demonstrate stability, with no slippage detected in the entirely unbonded STRP isolator. But 72mm x 72mm x 72mm looks more stable. Nonetheless, Aspect Ratio-1 and Aspect Ratio-1.5 are incapable of completing a full cycle; they fail prior to completion and can endure a maximum displacement of just 150%. Nonetheless, from Aspect-2, they complete the entire cycle. The effective damping obtained from these hysteresis curves is elaborated in the following section.

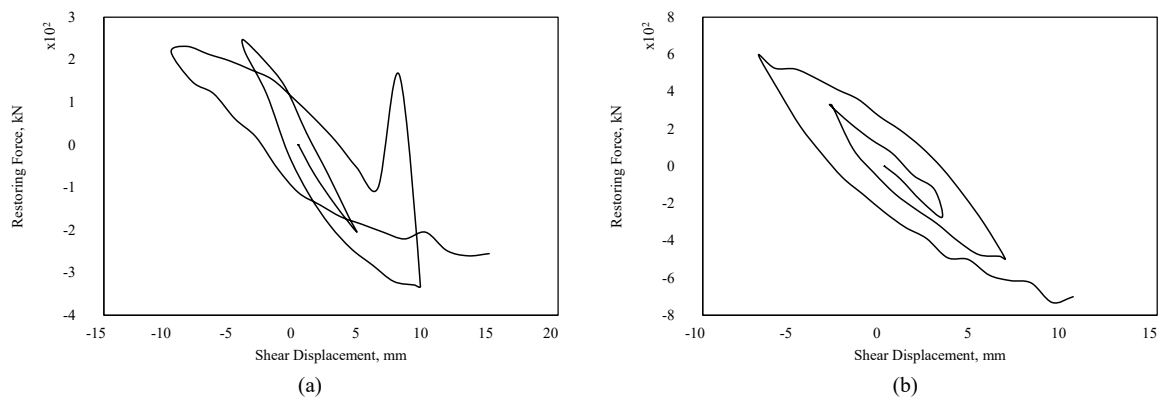


Figure 5: (a) Aspect-1 Y Axis hysteresis curve at 45° Loading; (b) Aspect-1.5 X Axis hysteresis curve at 45° Loading

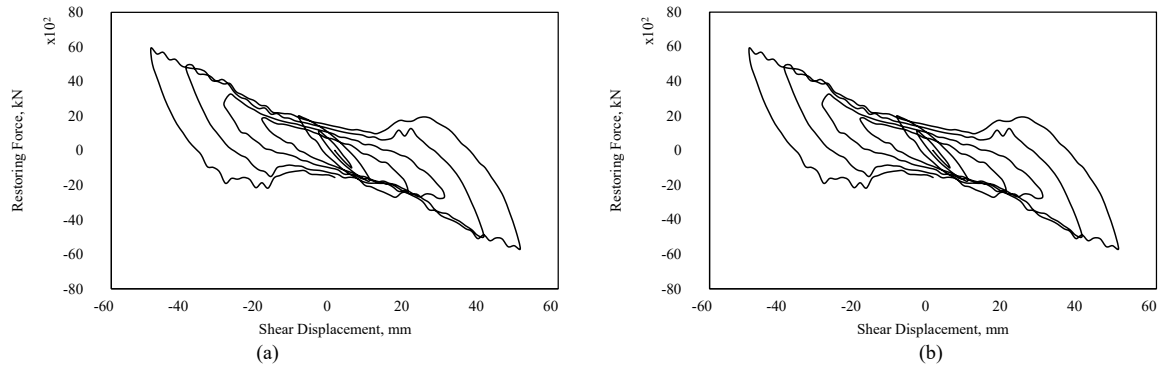


Figure 6: (a) Aspect-2 X Axis hysteresis curve at 45° Loading; (b) Aspect-2 Y Axis hysteresis curve at 45° Loading

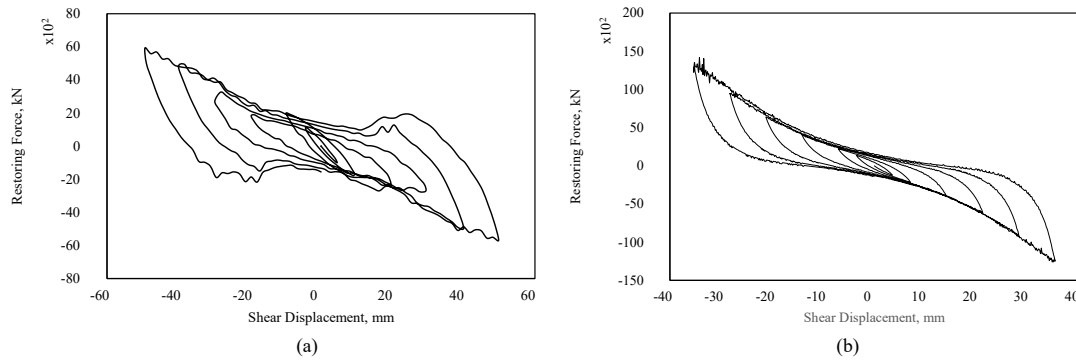


Figure 7: (a) Aspect-2.5 X Axis hysteresis curve at 45° Loading; (b) Aspect-3 Y Axis hysteresis curve at 60° Loading

#### 4.2 Effective damping

The effective damping  $\beta$  (%) of the STRP isolator is determined using the subsequent formula (ASCE/SEI 7-10, 2010):

$$\beta = \frac{2}{\pi} \left[ \frac{E_{loop}}{K_h (u^+ - u^-)^2} \right] \quad (1)$$

In this context, pertaining to the maximum positive displacement,  $u^+$ , and the maximum negative displacement,  $u^-$ , respectively, on the hysteresis curve. And  $E_{loop}$  is the Area found from hysteresis curve. Tables 4 to 18 display the effective damping values of STRP isolators. Figure 8 depicts the relationship between maximum and minimum damping concerning aspect ratio. At an aspect ratio of 1, damping diminishes as the loading direction increases, attaining its minimum at a 45° loading angle. Subsequently, an incline arises; however, the unbonded portion displays the maximum value. All aspect ratios of 1.5, 2, 2.5, and 3 demonstrate identical patterns. At a 0° orientation, STRP-0 demonstrates maximum damping, indicating superior shock absorption and perfect isolation performance. As the bonding area increases, the damping value gradually diminishes until achieving 100% bonding, at which juncture the damping value ascends, peaking in an unbonded state.

Table 4: Effective Damping for Aspect ratio-1 in loading direction at 0 and 15 degree

| Shear Displacement (%) | STRP-0      |             | STRP-25     |             | STRP-50     |             | STRP-75     |             | STRP-100    |             |
|------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
|                        | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) |
| 25                     | 12.33       | 12.24       | 12.27       | 12.05       | 12.12       | 11.89       | 11.98       | 11.76       | 12.07       | 12          |
| 50                     | 18.24       | 18.11       | 18.02       | 17.79       | 17.84       | 17.45       | 17.51       | 17.23       | 17.95       | 17.85       |
| 100                    | 15.16       | 14.73       | 15.69       | 15.62       | 15.02       | 14.98       | 14.87       | 14.77       | 14.56       | 14.35       |
| 150                    | 14.12       | 14.01       | 13.97       | 13.57       | 13.52       | 13.42       | 13.04       | 12.94       | 12.97       | 12.69       |

Table 5: Effective Damping for Aspect ratio-1 in loading direction at 30 and 45 degree

| Shear Displacement (%) | STRP-0      |             | STRP-25     |             | STRP-50     |             | STRP-75     |             | STRP-100    |             |
|------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
|                        | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) |
| 25                     | 12.11       | 11.89       | 11.89       | 11.57       | 11.74       | 11.53       | 11.56       | 11.14       | 11.98       | 11.56       |
| 50                     | 18.01       | 17.88       | 17.65       | 17.25       | 17.23       | 16.92       | 17.03       | 16.74       | 17.42       | 17.15       |
| 100                    | 14.53       | 14.22       | 15.33       | 15          | 14.78       | 14.48       | 14.55       | 14.24       | 14.13       | 13.86       |
| 150                    | 13.95       | 13.65       | 13.42       | 13.02       | 13.11       | 12.88       | 12.78       | 12.56       | 12.56       | 12.07       |

Table 6: Effective Damping for Aspect ratio-1 in loading direction at 60 and 75 degree

| Shear Displacement (%) | STRP-0      |             | STRP-25     |             | STRP-50     |             | STRP-75     |             | STRP-100    |             |
|------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
|                        | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) |
| 25                     | 11.96       | 12.03       | 11.68       | 11.79       | 11.62       | 11.67       | 11.26       | 11.42       | 11.61       | 11.72       |
| 50                     | 17.92       | 17.95       | 17.39       | 17.55       | 17.03       | 17.1        | 16.88       | 16.93       | 17.22       | 17.37       |
| 100                    | 14.26       | 14.33       | 15.05       | 15.11       | 14.61       | 14.68       | 14.37       | 14.42       | 13.91       | 14          |
| 150                    | 13.68       | 13.78       | 13.09       | 13.23       | 12.94       | 13.01       | 12.64       | 12.68       | 12.15       | 12.21       |

Table 7: Effective Damping for Aspect ratio-1.5 in loading direction at 0 and 15 degree

| Shear Displacement (%) | STRP-0      |             | STRP-25     |             | STRP-50     |             | STRP-75     |             | STRP-100    |             |
|------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
|                        | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) |
| 25                     | 14.41       | 14.36       | 14.37       | 14.33       | 14.23       | 14.18       | 14.15       | 14.03       | 14.18       | 14.12       |
| 50                     | 19.5        | 19.45       | 19.41       | 19.37       | 19.33       | 19.21       | 19.23       | 19.17       | 19.36       | 19.21       |
| 100                    | 16.78       | 16.71       | 16.82       | 16.78       | 16.66       | 16.57       | 16.59       | 16.52       | 16.43       | 16.35       |
| 150                    | 15.33       | 15.23       | 15.12       | 15.07       | 15.02       | 14.97       | 14.97       | 14.91       | 14.89       | 14.78       |

Table 8: Effective Damping for Aspect ratio-1.5 in loading direction at 30 and 45 degree

| Shear Displacement (%) | STRP-0      |             | STRP-25     |             | STRP-50     |             | STRP-75     |             | STRP-100    |             |
|------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
|                        | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) |
| 25                     | 14.22       | 14.17       | 14.21       | 14.16       | 14.16       | 14.06       | 14.01       | 13.94       | 14.09       | 14.01       |
| 50                     | 19.38       | 19.32       | 19.29       | 19.23       | 19.12       | 19          | 19.13       | 19.01       | 19.15       | 19.05       |
| 100                    | 16.56       | 16.48       | 16.71       | 16.64       | 16.42       | 16.33       | 16.49       | 16.42       | 16.32       | 16.28       |
| 150                    | 15.13       | 15.05       | 15          | 14.97       | 14.89       | 14.81       | 14.85       | 14.78       | 14.71       | 14.65       |

Table 9: Effective Damping for Aspect ratio-1.5 in loading direction at 60 and 75 degree

| Shear Displacement (%) | STRP-0      |             | STRP-25     |             | STRP-50     |             | STRP-75     |             | STRP-100    |             |
|------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
|                        | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) |
| 25                     | 14.26       | 14.21       | 14.25       | 14.19       | 14.22       | 14.12       | 14.1        | 13.98       | 14.12       | 14.06       |
| 50                     | 19.42       | 19.35       | 19.38       | 19.27       | 19.17       | 19.05       | 19.18       | 19.07       | 19.22       | 19.09       |
| 100                    | 16.6        | 16.51       | 16.79       | 16.67       | 16.49       | 16.39       | 16.56       | 16.44       | 16.48       | 16.3        |
| 150                    | 15.18       | 15.09       | 15.09       | 14.98       | 14.94       | 14.87       | 14.91       | 14.82       | 14.84       | 14.68       |

Table 10: Effective Damping for Aspect ratio-2 in loading direction at 0 and 15 degree

| Shear Displacement (%) | STRP-0      |             | STRP-25     |             | STRP-50     |             | STRP-75     |             | STRP-100    |             |
|------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
|                        | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) |
| 25                     | 17.32       | 17.23       | 16.52       | 16.42       | 16.45       | 16.31       | 16.4        | 16.27       | 16.42       | 16.29       |
| 50                     | 21.83       | 21.75       | 20.73       | 20.64       | 20.55       | 20.43       | 20.46       | 20.35       | 20.62       | 20.51       |
| 100                    | 20.61       | 20.49       | 20.34       | 20.21       | 19.54       | 19.43       | 18.75       | 18.63       | 18.52       | 18.43       |
| 150                    | 19.33       | 19.21       | 18.51       | 18.42       | 17.26       | 17.12       | 17.12       | 17          | 16.88       | 16.79       |
| 200                    | 18.25       | 18.12       | 16.85       | 16.71       | 16.24       | 16.1        | 15.97       | 15.78       | 15.73       | 15.61       |
| 250                    | 17.96       | 17.84       | 15.98       | 15.86       | 15.22       | 15.15       | 15.23       | 15.08       | 15.34       | 15.11       |

Table 11: Effective Damping for Aspect ratio-2 in loading direction at 30 and 45 degree

| Shear Displacement (%) | STRP-0      |             | STRP-25     |             | STRP-50     |             | STRP-75     |             | STRP-100    |             |
|------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
|                        | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) |
| 25                     | 17.65       | 17.52       | 16.33       | 16.15       | 16.23       | 16.08       | 16.15       | 16          | 16.17       | 16.02       |
| 50                     | 21.64       | 21.5        | 20.52       | 20.21       | 20.31       | 20.13       | 20.22       | 20.04       | 20.41       | 20.15       |
| 100                    | 20.38       | 20.22       | 20.13       | 19.89       | 19.35       | 19.15       | 18.55       | 18.31       | 18.33       | 18.13       |
| 150                    | 19.14       | 18.89       | 18.31       | 18.13       | 17.03       | 16.89       | 16.91       | 16.75       | 16.68       | 16.49       |
| 200                    | 18          | 17.74       | 16.61       | 16.41       | 15.97       | 15.78       | 15.68       | 15.45       | 15.55       | 15.37       |
| 250                    | 17.66       | 17.42       | 15.76       | 15.56       | 15.06       | 14.83       | 14.94       | 14.65       | 15          | 14.69       |

Table 12: Effective Damping for Aspect ratio-2 in loading direction at 60 and 75 degree

| Shear Displacement (%) | STRP-0      |             | STRP-25     |             | STRP-50     |             | STRP-75     |             | STRP-100    |             |
|------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
|                        | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) |
| 25                     | 17.72       | 17.61       | 16.4        | 16.21       | 16.32       | 16.14       | 16.21       | 16.05       | 16.25       | 16.1        |
| 50                     | 21.75       | 21.63       | 20.54       | 20.4        | 20.4        | 20.21       | 20.3        | 20.13       | 20.5        | 20.33       |
| 100                    | 20.45       | 20.3        | 20.2        | 20          | 19.41       | 19.23       | 18.67       | 18.42       | 18.41       | 18.24       |
| 150                    | 19.2        | 19.06       | 18.4        | 18.22       | 17.1        | 16.94       | 17.05       | 16.82       | 16.74       | 16.58       |
| 200                    | 18.12       | 17.85       | 16.67       | 16.52       | 16.09       | 15.87       | 15.78       | 15.57       | 15.63       | 15.43       |
| 250                    | 17.72       | 17.54       | 15.84       | 15.65       | 15.14       | 15          | 15.09       | 14.87       | 15.11       | 14.78       |

Table 13: Effective Damping for Aspect ratio-2.5 in loading direction at 0 and 15 degree

| Shear Displacement (%) | STRP-0      |             | STRP-25     |             | STRP-50     |             | STRP-75     |             | STRP-100    |             |
|------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
|                        | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) |
| 25                     | 16.71       | 16.55       | 16.52       | 16.3        | 16.45       | 16.21       | 16.4        | 16.19       | 16.42       | 16.22       |
| 50                     | 20.98       | 20.78       | 20.73       | 20.53       | 20.55       | 20.32       | 20.46       | 20.23       | 20.61       | 20.41       |
| 100                    | 19.76       | 19.54       | 20.34       | 20.11       | 19.54       | 19.44       | 18.75       | 18.61       | 18.74       | 18.52       |
| 150                    | 19.04       | 18.83       | 18.51       | 18.33       | 17.26       | 17.04       | 17.12       | 16.94       | 17.01       | 16.88       |
| 200                    | 18.11       | 17.95       | 16.85       | 16.67       | 16.24       | 16          | 15.97       | 15.8        | 15.95       | 15.73       |
| 250                    | 17.79       | 17.86       | 15.98       | 15.73       | 15.22       | 15.13       | 15.23       | 15.13       | 15.25       | 15.15       |

Table 14: Effective Damping for Aspect ratio-2.5 in loading direction at 30 and 45 degree

| Shear Displacement (%) | STRP-0      |             | STRP-25     |             | STRP-50     |             | STRP-75     |             | STRP-100    |             |
|------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
|                        | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) |
| 25                     | 16.42       | 16.2        | 16.14       | 16.05       | 16.05       | 15.85       | 15.98       | 18.45       | 16.08       | 15.92       |
| 50                     | 20.71       | 20.53       | 20.32       | 20.22       | 20.23       | 20.05       | 20.17       | 19.95       | 20.32       | 20.12       |
| 100                    | 19.46       | 19.24       | 20          | 19.84       | 19.35       | 19.14       | 18.47       | 18.25       | 18.41       | 18.23       |
| 150                    | 18.75       | 18.55       | 18.19       | 17.86       | 16.97       | 16.73       | 16.76       | 16.6        | 16.74       | 16.54       |
| 200                    | 17.88       | 17.65       | 16.56       | 16.33       | 15.89       | 15.63       | 15.63       | 15.32       | 15.66       | 15.46       |
| 250                    | 17.77       | 17.52       | 15.61       | 15.29       | 15          | 14.77       | 14.95       | 14.76       | 15.02       | 14.86       |

Table 15: Effective Damping for Aspect ratio-2.5 in loading direction at 60 and 75 degree

| Shear Displacement (%) | STRP-0      |             | STRP-25     |             | STRP-50     |             | STRP-75     |             | STRP-100    |             |
|------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
|                        | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) |
| 25                     | 16.48       | 16.31       | 16.2        | 16.14       | 16.15       | 15.94       | 16.04       | 15.83       | 16.18       | 16          |
| 50                     | 20.85       | 20.6        | 20.41       | 20.32       | 20.34       | 20.13       | 20.3        | 20.03       | 20.37       | 20.22       |
| 100                    | 19.54       | 19.35       | 20.11       | 19.91       | 19.48       | 19.23       | 18.53       | 18.36       | 19.02       | 18.31       |
| 150                    | 19.01       | 18.64       | 18.37       | 17.95       | 17.1        | 16.88       | 16.98       | 16.69       | 16.89       | 16.63       |
| 200                    | 18          | 17.79       | 16.64       | 16.42       | 16.06       | 15.72       | 15.83       | 15.45       | 15.94       | 15.56       |
| 250                    | 17.95       | 17.65       | 16          | 15.38       | 16.1        | 14.88       | 15.64       | 14.88       | 15.72       | 14.94       |

Table 16: Effective Damping for Aspect ratio-3 in loading direction at 0 and 15 degree

| Shear Displacement (%) | STRP-0      |             | STRP-25     |             | STRP-50     |             | STRP-75     |             | STRP-100    |             |
|------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
|                        | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) |
| 25                     | 17.73       | 17.65       | 17.66       | 17.58       | 17.54       | 17.43       | 17.31       | 17.23       | 17.43       | 17.34       |
| 50                     | 22.67       | 22.61       | 22.42       | 22.34       | 22.04       | 22          | 21.83       | 21.75       | 22.22       | 22.22       |
| 100                    | 21.32       | 21.24       | 21.94       | 21.85       | 21.13       | 21.05       | 20.31       | 20.22       | 20.34       | 20.28       |
| 150                    | 20.04       | 20          | 19.5        | 19.37       | 18.31       | 18.23       | 18.04       | 17.97       | 17.95       | 17.86       |
| 200                    | 18.94       | 18.88       | 17.21       | 17.14       | 16.67       | 16.6        | 16.33       | 16.28       | 16.31       | 16.25       |
| 250                    | 18.63       | 18.57       | 16.32       | 16.25       | 15.81       | 15.75       | 15.8        | 15.74       | 15.92       | 15.82       |

Table 17: Effective Damping for Aspect ratio-3 in loading direction at 30 and 45 degree

| Shear Displacement (%) | STRP-0      |             | STRP-25     |             | STRP-50     |             | STRP-75     |             | STRP-100    |             |
|------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
|                        | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) |
| 25                     | 17.58       | 17.88       | 17.5        | 17.73       | 17.37       | 17.13       | 17.15       | 17.04       | 17.23       | 17.42       |
| 50                     | 22.55       | 22.33       | 22.27       | 22.17       | 21.91       | 22.13       | 21.64       | 21.64       | 22.15       | 21.84       |
| 100                    | 21.13       | 21.23       | 21.79       | 21.43       | 20.97       | 20.67       | 20.13       | 20.11       | 20.19       | 20.42       |
| 150                    | 19.89       | 19.7        | 19.31       | 18.7        | 18.15       | 18.31       | 17.89       | 17.82       | 17.75       | 17.68       |
| 200                    | 18.78       | 18.31       | 17.09       | 16.89       | 16.51       | 16.35       | 16.19       | 16.14       | 16.13       | 16.22       |
| 250                    | 18.44       | 18.25       | 16.17       | 16.12       | 15.64       | 16.08       | 15.64       | 15.65       | 15.72       | 15.63       |

Table 18: Effective Damping for Aspect ratio-3 in loading direction at 60 and 75 degree

| Shear Displacement (%) | STRP-0      |             | STRP-25     |             | STRP-50     |             | STRP-75     |             | STRP-100    |             |
|------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
|                        | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) | $\beta$ (%) |
| 25                     | 18.02       | 17.95       | 17.91       | 17.82       | 17.31       | 17.22       | 17.27       | 17.19       | 17.67       | 17.6        |
| 50                     | 22.51       | 22.42       | 22.38       | 22.29       | 22.37       | 22.25       | 21.79       | 21.68       | 22.11       | 22.02       |
| 100                    | 21.42       | 21.35       | 21.67       | 21.56       | 20.89       | 20.79       | 20.31       | 20.22       | 20.6        | 20.51       |
| 150                    | 19.9        | 19.83       | 18.89       | 18.79       | 18.45       | 18.4        | 18          | 17.91       | 17.91       | 17.8        |

|     |       |       |       |       |       |       |       |       |       |       |
|-----|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| 200 | 18.51 | 18.43 | 17.05 | 16.98 | 16.51 | 16.43 | 16.33 | 16.25 | 16.42 | 16.31 |
| 250 | 18.49 | 18.39 | 16.38 | 16.27 | 16.28 | 16.19 | 15.81 | 15.73 | 15.89 | 15.72 |

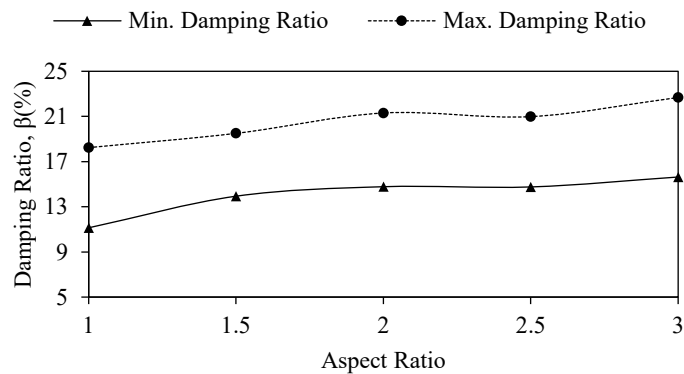


Figure 8: Highest and Lowest Effective Damping according to Aspect ratio for STRP

## 5. CONCLUSIONS

This study investigates the lateral load performance of STRP isolators with varying bonding areas between the isolator and structural levels subjected to cyclic bi-directional lateral stress. Square and cuboidal isolators are examined under cyclic loading orientations from 0° to 75° in 15° increments, comparing aspect ratios of 1, 1.5, 2, 2.5, and 3. The primary conclusions are as follows:

- STRP-0 (unbonded) has enhanced efficacy in seismic isolation, which decreases with an increasing number of bonded connections between the isolator and structural components. The STRP-100 isolator demonstrates the lowest effectiveness in seismic isolation.
- Effective damping diminishes with increasing loading angles for aspect ratios of 1, 1.5, 2, 2.5, and 3, attaining its minimum at 45 degrees. It subsequently rises at 60 degrees but declines again at 75 degrees, although it does not fall as low as the damping observed at 45 degrees. Aspect ratios of 1 and 1.5 demonstrate a total displacement of 150%, but all other aspect ratios indicate a lateral displacement of 250%.
- The least damping recorded at an aspect ratio of 1 for a 45-degree loading direction in a 75-degree pad isolator is 11.14%, whereas the maximum damping occurs at an aspect ratio of 3 for a 0-degree loading direction at 250% displacement, measuring 22.67%.
- Aspect Ratio-1 exhibits the lowest performance and demonstrates instability in structure and inadequate shock absorbance; consequently, Aspect-3 greatly outperforms it in this regard.
- These findings provide guidance for the selection of STRP isolators in structural applications, depending on the necessary damping and flexibility.

## DECLARATION OF USE OF AI

The authors claim that AI-based methods (QuillBot) were only used for language editing and paraphrasing to improve readability and clarity. AI techniques were not used in the research methodology, data collection, analysis, or interpretation.

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