INVESTIGATION ON SEISMIC VIBRATION MITIGATION OF A BUILDING STRUCTURE WITH RUBBER STRIP COLUMN JACKETING

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ABSTRACT

The study concentrates on the investigation of damping force production and the effectiveness of using rubber strips on columns, against seismic vulnerabilities of a multi-degree-of-freedom system structure (MDOF). The rubber strips are used by jacketing the columns of an experimental three-storied steel structure. The investigation has employed both experimental and numerical analysis (ETABS 2016) to achieve a vivid understanding of the effect. In this experiment, the specifications (material property) of rubber strips are similar (grades, lengths, width, etc.) however, different in thickness. Strips of three thicknesses are used in this test to identify the effectiveness, compare the impact, and achieve optimum results. The experimental study is done using the Earthquake-Shake Table Machine. A prototype of El-Centro earthquake displacement data for 15 seconds duration is applied at the bottom of the structure and the relative displacement data (output) has been recorded with the help of a time history analysis software. The study presents both experimental and numerical displacement curves, as well as numerical acceleration curves. The comparative analysis compares the percent reduction in displacements before and after employing rubber jackets of each thickness on columns. The investigation determines the optimum strip thickness and the maximum reduction percentage in displacements. In conclusion, column jacketing with rubber strips is a potentially cost-effective, easy-to-install, easy-to-maintain, and sustainable method for existing and newly built structures to mitigate seismic vibration.

Keywords: *Rubber strips, column jacketing, damping, reduction percentage, cost-effective*

1. INTRODUCTION

Earthquake is a significant global concern in the field of structural engineering. Designing earthquake-resistant structures and retrofitting existing ones are potential areas of research to ensure structural stability and strengthen them. In the past many decades, numerous studies have been conducted on various earthquake mitigation methods. At that time, researchers had identified the main issues that a structure faces during an earthquake. These included vibration control of the structure, and strengthening of columns against imposed lateral loads, all of which are related to the term "damping".

Damping is the process of dissipating energy to prevent vibratory motion such as mechanical oscillations. Structures must attain stability after an imposed load (wind, seismic). There are multiple options to increase the damping of a structure such as; base isolations, dampers, bracings, and tuned mass dampers. Additionally, dampers are of many kinds like friction dampers, tuned liquid dampers, etc. Tuned liquid column dampers were first introduced by Fumitoshi Sakai (Sakai, Takeda, & Tamaki, 1989). Tuned liquid column dampers or TLCD are found effective in suppressing maximum displacement due to the wind load and Balendra et al. suggested that the opening ratios of the columns of the dampers are responsible for the effectiveness according to the heights of the buildings (Balendra, Wang, & Cheong, 1995). Gao et al. also studied the optimization of the TLCD emphasizing the tuning ratio (H. Gao, June 1997). Recently, Wu et al. proposed a design guideline for TLCD (Wu, Shih, Lin, & Shen, 2005). By that time, it had also gained attention to use against seismic activity, Ayman et al. showed the effectiveness of the TLCD for seismic activity considering soft soil (Ayman Abd-Elhamed, December 2022). Base Isolation is another advancement in seismic-resistant construction. The adoption of this method keeps skyscrapers floated on a system (ball bearings, springs, padded cylinders) that absorbs sudden loads (Khan, 2013). Tajirian proposed a design guideline of base isolation for structures and stated that it may help to avoid expensive retrofitting (Tajirian, July 1998).

Among all the seismic mitigation methods, jacketing columns to increase the damping is a new concept. Column jacketing is a popular method of retrofitting, that helps to increase the strength of the columns of a structure. Reinforced Concrete Jacketing improves the load-carrying capacity, strength, and stiffness of any column, it minimizes the cost of labor for installations (Ahed Habib, 2020). RC jacketing shows noticeable effectiveness by increasing the cross-section of it. Thus, the axial strength, bending, rigidity, and also ductility of the original column increase (Aguero, 25 February 2022).On the other hand, FRP jacketing is a developed method to increase the strength and ductility of damaged or weak designed RC structures (Prathamesh Dingorkar, October 2016). In a recent study, the steel jacketing on the column is found to delay the crack patterns and increase life spans (PSL Manogna, June 2018). Therefore, Jacketing is a popular retrofitting and effective technique to attain achieved results.

Rubber Jacketing of Columns is rarely investigated and this study aims to focus on the effectiveness of the rubber in increasing the overall damping of a structure. The rubber jacketed columns or RJC may work on the principle of the elasticity of the rubber, by adding more elastic properties along with the columns. RJC should minimize the sudden imposed load, and relative acceleration and shorten the vibration period to restore the stability phase. This paper presents and discusses the findings in detail.

2. METHODOLOGY

The experiment is divided into two methods; a) Experimental Analysis and b) Numerical Analysis. The findings from both analyses are compared and presented as a result of this. In this experiment, the relative displacement of the experimental structure (along with 36 kg weight altogether) found due to the input data in both analyses is referred to as “Uncontrolled (Unc) data”. On the other hand, the relative displacement data found after employing rubber jacketing on columns are referred to as “Controlled data or RJC data”. At the end of the experiment, the relative displacements are compared with the Unc data to have a vivid understanding of the effectiveness of the modification. Moreover, the study discussed the reduction percentage broadly.

2.1 Experimental Analysis

The analysis involved testing a 3-storey steel structure that was 54 inches in height. The structure was a multi-degree-of-freedom (MDOF) system with 4 slabs, each measuring 18x18 square inches in area. The entire structure, along with a total weight of 36 kg (12 kg of sandbags on each slab, excluding the bottom slab), was fixed onto an earthquake shake table for testing.

At the base of the structure, a prototype of ground-shaking data from El-Centro has been used as the input displacement/data in the earthquake shake table. The output displacement/data (mm) for the rubber jacketed columns or RJC using 3 types of thicknesses of rubber strips have been recorded for 15 seconds of vibration period.

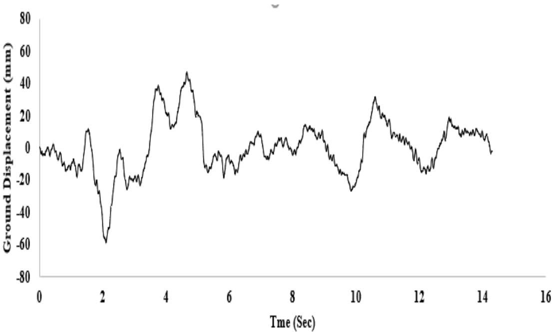

Figure 1: El-Centro prototype curve

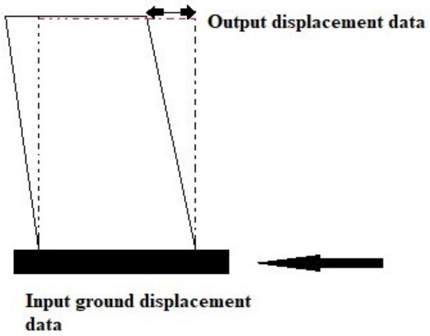

Figure 2: Input and output displacement

In this test, the columns of the experimental structure are wrapped (spiral) with rubber strips of 3 different thicknesses; 0.5mm, 1mm, and 2mm to understand the variances of effects (output displacements) of the modifications. The output values of the test are recorded by the application of modified software (Time History Analysis) and sensors. Two sensors are set at the bottom and the top of the structure to measure the displacements at the base and the top.

Figure 3: Earthquake

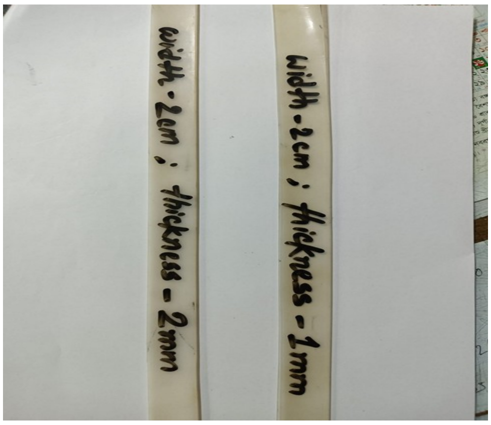

Figure 4: Silicon rubber strips

The rubber strips used here are made of silicon and each of the silicon rubber strips are same in length (140cm) and width (2cm). These rubber strips of each mentioned thickness are used by wrapping the columns and clipping to the column ends. In response to the earthquake shake table machine performing the input data at the ground for 15 seconds, the RJC data for each strip thickness are collected.

Figure 5: Experimental setup on the earthquake shake table

Figure 6: Column jacketing with rubber

2.2 Numerical Analysis

The numerical analysis has been conducted by the application of the ETABS 2016 software. On the experimental structure, the acceleration curve of the El-Centro earthquake has been used as the input data. The numerical analysis of this paper presents a detailed analysis of the acceleration and displacement curves for the modifications.

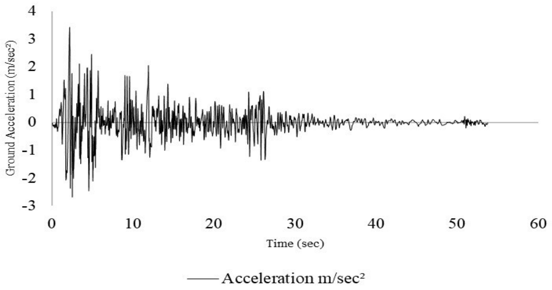

Figure 7: El-Centro acceleration curve

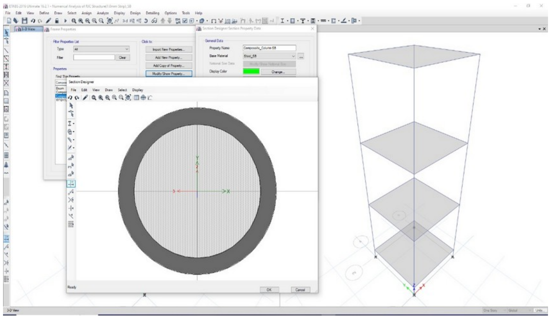

Figure 8: Numerical Analysis of RJC

The material properties used in the software, of silicon rubber strips of various thicknesses and the experimental structure specifications are presented in Table 1. The steel structure and rubber strips in this analysis conform to ASTM standards.

Table 1: Material Properties

Materials	Descriptions	Values	Units
Steel	Mass per unit volume	749.047	kg/m^3
	Modulus of Elasticity, E	200,000	MPa
	Poisson's Ratio, U	0.3	
	Shear Modulus, G	76903.07	MPa
	Minimum Yield Stress, F_y	345	MPa
	Minimum Tensile Strength, F_u	448	MPa
Rubber	Mass per unit volume	1100	kg/m^3
	Modulus of Elasticity, E	50	MPa
	Poisson's Ratio, U	0.33	
	Shear Modulus, G	18.8	MPa

The numerical RJC acceleration curves and displacement curves are thoroughly analyzed to distinguish the major impacts and illustrated hereby.

3. ILLUSTRATIONS

All the graphs are divided into two analysis methods; a) Experimental Analysis and b) Numerical Analysis. Both of the results are discussed here successively.

3.1 Result of Experimental Analysis

0.5mm RJC structure displacement data:

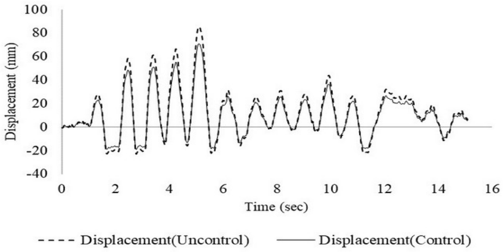

Figure 9: Unc VS 0.5mm RJC (experimental)

The graph indicates that the maximum uncontrolled displacement is 85mm. The rubber strip covering with a thickness of 0.5mm results in a maximum displacement of approximately 71mm. Both curves have a similar initial response on the graph. The highest peaks are shown by both lines between 5 and 6 seconds. After 6 seconds, the curves suddenly plunged and fluctuated till the end.

1mm RJC structure displacement data:

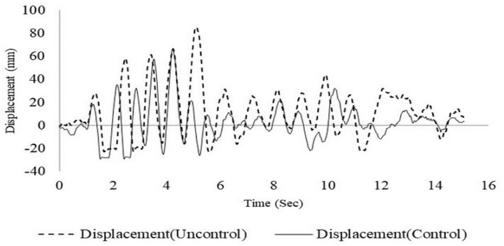

Figure 10: Unc VS 1mm RJC (experimental)

The graph indicates that the experimental RJC structure has a maximum displacement of approximately 66mm. The initial response of the controlled data curve shows a significant difference compared to the uncontrolled data (85mm). The peak of the uncontrolled data is highest between 5 and 6 seconds, whereas the controlled data curve peaks at 4 seconds. Moreover, the controlled curve visibly reduces the impact of the imposed load.

2mm RJC structure displacement data:

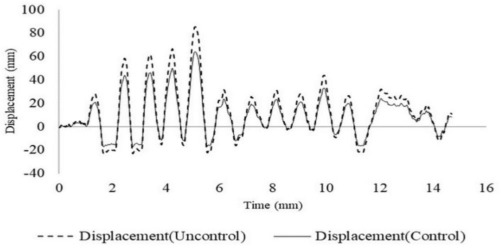

Figure 11: Unc VS 2 mm RJC (experimental)

The experimental RJC structure gives a maximum displacement of approximately 64 mm to the uncontrolled data (85mm). The experimental RJC structure had a maximum displacement of approximately 64mm, which is less than the uncontrolled data that had an 85mm displacement. The graph shows that initially and at the end, both curves have similar responses. However, there is a clear difference in the peak points, where the controlled curve has a visibly reduced peak compared to the uncontrolled curve.

3.2 Result of Numerical Analysis

0.5mm RJC structure displacement & acceleration data:

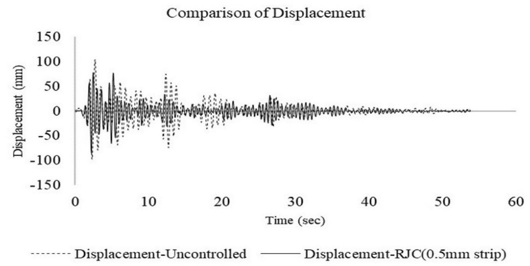

Figure 12: Unc VS 0.5 mm RJC (numerical)

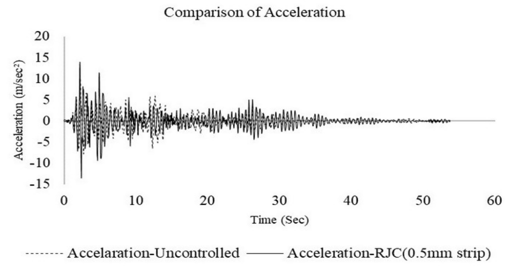

Figure 13: Unc VS 0.5mm RJC (numerical)

During numerical analysis, it was found that the uncontrolled maximum displacement is approximately 103mm. However, in response to the input data, the controlled or RJC maximum displacement was recorded at 78mm. The acceleration curve showed that the initial impact was high in both cases, but the later effects were minimized in the controlled curve. Therefore, a significant difference was noticed, which indicates the effectiveness of the modification.

1mm RJC structure displacement & acceleration data:

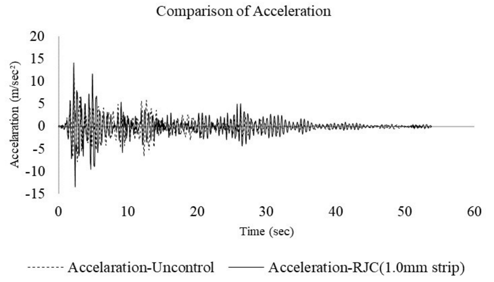

Figure 15: Unc VS 1 mm RJC (numerical)

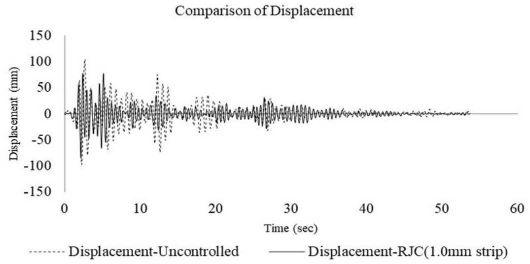

Figure 14: Unc VS 1 mm RJC (numerical)

In this illustration, it is observed that the maximum RJC displacement is approximately 76mm, which is lower than the uncontrolled data (103mm). Both the graphs of the displacement and acceleration data indicate that the initial curves have a higher response to the load. However, the controlled data demonstrates a reduced curve line compared to the uncontrolled data.

2mm RJC structure displacement & acceleration data:

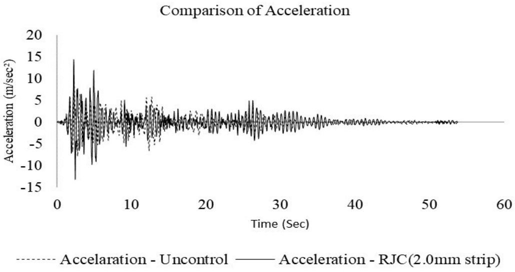

Figure 17: Unc VS 2 mm RJC (numerical)

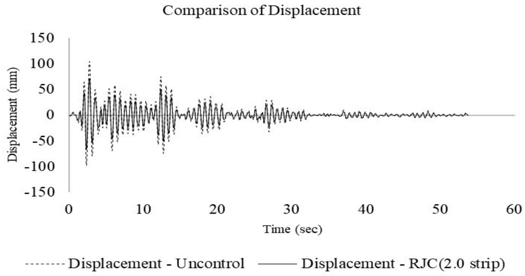

Figure 16: Unc VS 2 mm RJC (numerical)

For 2mm strips, the maximum displacement data for 2mm strips is recorded at 70mm, compared to the uncontrolled data (103mm). The displacement curves for both controlled and uncontrolled data fluctuate from the beginning until 15 seconds. However, the controlled curve on the acceleration graph significantly reduces the impact of the load afterward.

Table 1 presents the overview of the illustrations and the values achieved overall. The experimental uncontrolled and numerical uncontrolled show a difference of around 20mm. This refers to the possible deflection of the experimental work, material properties, etc. Furthermore, among all thicknesses, 0.5mm RJC shows the higher displacement values whereas 2mm RJC has the lowest values in both numerical and experimental analyses.

Table 2: Maximum Displacement (Unc vs RJC)

Conditions	**Unc Maximum Displacements(mm)**	**RJC Maximum Displacements (mm)**		
		0.5mm (Strip)	1.0mm (Strip)	2.0mm (Strip)
Experimental	85.3553	70.845	66.419	64.0167
Numerical	103.981	78.125	74.219	70.707

Table 3 represents a clear understanding of the effectiveness that the RJC has shown on the experimental structure overall. The 0.5mm strips reduce around 17% (experimental) and 25% (numerical) of the maximum uncontrolled displacement. On the other hand, 2mm strips reduce approximately 25% (experimental) and 32% (numerical) of the maximum uncontrolled displacement, which is the highest among all conditions.

Table 3: Reduction Percentages (Unc vs RJC)

Conditions	**Reduction percentages of RJC Maximum Displacement (%)**		
	0.5mm (Strip)	1.0mm (Strip)	2.0mm (Strip)
Experimental	16.99	22.18	25.13
Numerical	24.87	28.63	32.01

From the overall study, it is to be stated that a rubber jacketing column may be executed as an efficient, cost-effective technique to increase the damping of the structure regarding seismic load. In this study, the optimum rubber strip thickness that has the least value for the experimental structure is found 2 mm.

4. CONCLUSIONS

In the experiment of this study, the results put the facts in front that RJC is a beneficial method, minimizing the displacement due to the ground shaking. Moreover, RJC is shortening the vibration period and fastening the time to restore the stability phase for the structure. In short, the aim of this study has been accomplished. For this test, silicon rubber is used which is known to be more durable than many other grades of rubber. However, the usage of rubber polymer in the Civil Engineering industry may open a vast scope of the rubber polymer recycling industry. It may help to elevate global environmental well-being. Subsequently, testing different grades of rubber in jacketing will be emphasized more.

Jacketing of columns in general is used to increase the strength of existing structures in many countries. However, the idea of jacketing columns to increase the damping of the overall structure against earthquake loads is not introduced yet. Rubber jacketing of columns may become a beneficial method globally. However, it requires more and more studies. In conclusion, the rubber jacketing of columns to mitigate the earthquake-induced load of a structure has shown effectiveness and requires more investigation in the future in this regard.

5. ACKNOWLEDGMENT

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