# Experimental Evaluation of Compression Properties of Reclaimed Rubber Base Isolator

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**ABSTRACT**

Traditional rubber seismic isolators are rarely employed for residential buildings as they are big in size, heavy and expensive. Fiber reinforced elastomeric isolators (FREIs) have been identified to provide cost effective base isolation. In this paper, base isolators are developed using reclaimed rubber reinforced with carbon fiber reinforcement polymer (CFRP). Vertical stiffness of the isolator is determined experimentally. Isolators with 4, 6, 8, 10 11 and 12 layers of reclaimed rubber pads with and without CFRP reinforcement are considered in the study. Effect of aspect ratio on vertical stiffness is also investigated.

**Keywords:** Base isolator, CFRP, Reclaimed rubber

## 1 Introduction

An earthquake is the audible shaking of the earth's surface caused by volcanism or subsurface movement along a fault plane. Seismic waves are produced when there is a sudden release of energy in the earth's crust, and these waves force the ground and any structures on it to vibrate. The main consequences include shaking and ground rupture, which primarily cause buildings and other rigid structures to experience more or less severe damage. The main objective of earthquake resistant design is to make such buildings resist the effects of earthquakes without getting collapsed even during strong earthquakes. Seismic base isolation is one of the widely accepted seismic protection technologies. Among the various type of base isolators, elastomeric bearing is the most widely used base isolation system. Elastomers are ideal for base isolation due to their low shear modulus, near incompressibility, and capacity to accept sizable recoverable strains at very low stress levels. Studies shown that elastomers with adequate reinforcement showed better performance under seismic excitations. Alternating layers of rubber with steel reinforcement is the traditional approach of elastomeric isolator. The reinforcement improves the isolator's compression characteristics, giving the composite device, the strength and stability it needs to sustain the overlying structure. The use of steel reinforced elastomeric isolators has been rarely used by developed countries as it is large, heavy, and expensive due to high labour-intensive manufacturing process. With the aim of reducing the cost and easy manufacturing, a new approach was introduced for the reinforcement of isolators by Kelly [1]. The steel shims in between the elastomers were replaced by much lighter fibers which are more flexible in extension and having no flexural rigidity, so called fiber reinforced elastomeric isolator (FREI). The main advantages of fiber reinforced elastomeric isolators include its superior damping property, low manufacturing cost, light weight, and the possibility to cut to required size. The use of fiber reinforcement in an unbounded configuration has the advantage of eliminating the tensile stress in the bearing when sheared. The unbonded application can result in a stable rollover deformation and can result in a reduced horizontal stiffness which will improve the efficiency of the base isolator [2]. The effect of unbonded fiber reinforced isolators on masonry building under seismic loading was studied by Zisan *et al.* [3]. The base of the building is reported to have undergone large horizontal deformation without causing failure of the



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isolator. Main fibers which were used for the development of isolator include carbon fiber reinforced polymer (CFRP) and glass fiber reinforced polymer (GFRP). Studies were carried out on aramid fiber reinforced polymer (AFRP, otherwise called as Kevlar) also. The horizontal test results showed that carbon reinforcement elastomers were over two times higher in damping and three times higher in vertical stiffness than steel reinforcement [4].

The usage of fiber in place of steel will lead to cost reduction. Further, reduction of the cost could be achieved by replacing virgin natural rubber with recycled rubber. Rubber cannot be easily reprocessed because of its chemical characteristics, which makes it an insoluble and infusible material, making recycling processes difficult and less economical. Several efforts were made on reusing the waste rubber/ tyre such as scrap tyre pads. Scarp tyre pads, (STPs) in which a layer of steel reinforcing cords is interleaved in rubber sheets, were directly used for the development of base isolator in unbonded configuration. The isolator showed lateral deformation capacity up to shear strain level of 100 % [5]. However, STPs suffered from several drawbacks such as uneven thickness of worn out tyre sample, different thread pattern by different manufacturers and difficulty to cut the specimen to required size.

Several recycling processes were adopted for the mere fabrication of recycled rubber pads. Cold pressing or hot forging rubber granules from waste tyres and a polyurethane binder in a mould will result in a tyre derived material (TDM), which is one among the several processes of obtaining recycled rubber. This TDM is then bonded to fiber layers using the same binder and subjected to cold pressing [6]. Recycled rubber compounds exhibited lower mechanical properties compared to virgin rubber both in terms of tensile strength and deformation capacity. Apart from recycled rubber another reprocessed rubber is reclaimed rubber (also called as devulcanized rubber), made from scrap or waste rubber. Cilento *et al.,* [7] developed a low cost reclaimed rubber compound to be adopted for a seismic base isolator with polymeric synthetic fabrics (nylon and polyester) in unbounded configuration. This material showed adequate properties in comparison to natural rubber for shear modulus and hardness. For reclaimed rubber base isolator, no damage was observed after repeated cycle of loading and the bond between fabric and rubber was strong enough to prevent delamination of layers. A stable rollover deformation of the reclaimed rubber compound was observed from the experiments conducted by Cilento *et al.,* [7].

For the design of base isolator vertical stiffness is an important parameter. The isolator must support the compressive load coming over to it. The main purpose of reinforcements is to prevent the lateral bulging of the elastomeric layers brought on by a compressive load. In the present study, base isolators are developed using reclaimed rubber sheets cut to the required size with fiber sheets placed in between the rubber layers. CFRP sheets are used as fibers. The study attempts to investigate the effect of vertical stiffness by varying number of layers of the reclaimed rubber.

## 2 Experimental Setup

### 2.1 Preparation of base isolator specimen

The reclaimed rubber specimens are cut into maximum possible dimension of 150×150×10 mm size. All the reclaimed rubber specimens are of equal thickness (figure 1). Hence the height of an isolator with a particular number of layers will be same for any isolator. Five different types of isolators with 4, 6, 8, 10 and 12 layers of reclaimed rubber sheets are considered in the present study. These samples are designated as Sample 1, 2, 3, 4 and 5 respectively. Two sets of such samples are considered. First and second set of samples include reclaimed rubber base isolator without reinforcement and with CFRP reinforcement respectively. CFRP wrap is cut into same size of reclaimed rubber and one CFRP sheet is placed in between two rubber layers for providing reinforcement. Bi-directional CFRP fabrics (figure 2) are selected for the present study. The details of isolator samples considered, and their aspect ratios (ratio of top area to total lateral area) are tabulated in table 1. The final prepared base isolator specimen with intermediate CFRP wraps is shown in figure 3.

**Figure 1:** *Reclaimed rubber*

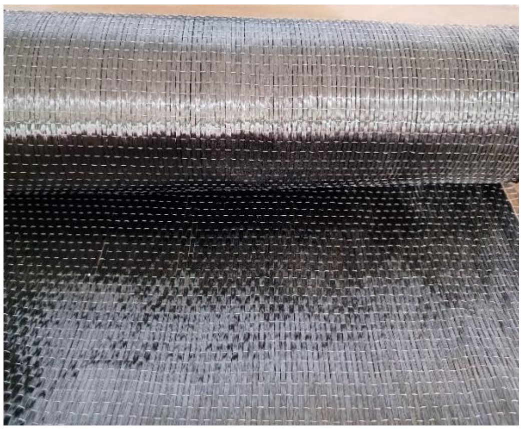


**Figure 2:** *Bi-directional CFRP wrap*

**Table 1:** *Aspect ratio of different samples*

| | | | | | |
|---|---|---|---|---|---|
| Sample without CFRP reinforcement | 1A | 2A | 3A | 4A | 5A |
| Sample with CFRP reinforcement | 1B | 2B | 3B | 4B | 5B |
| Number of layers | 4 | 6 | 8 | 10 | 12 |
| Aspect ratio | 3.75 | 2.5 | 1.875 | 1.5 | 1.25 |

**Figure 3:** *Base isolator specimen with CFRP*

## 2.2 Compression Test

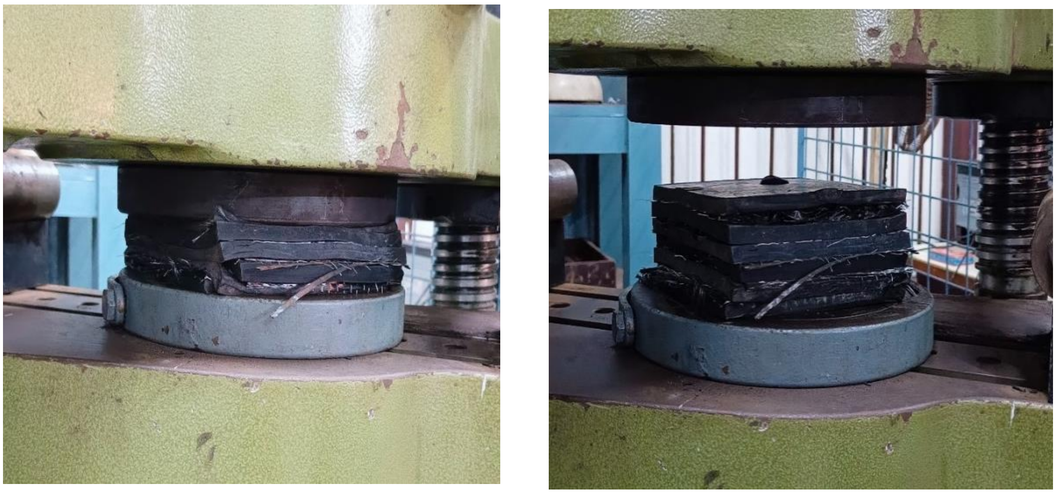
Vertical stiffness of the isolator specimen is estimated from the vertical compression test. The test setup for the compression test is shown in figure 4. Test is carried out on a computer controlled universal testing machine (UTM) of 600 kN capacity. Specimens are placed in between two supporting plates to evenly distribute the load along the surface of the isolator. Initially, the test is conducted on reclaimed rubber base isolator without reinforcement and later, on reclaimed rubber base isolator with CFRP sheets in between the rubber layers. The specimens are loaded under controlled vertical displacement not more than 50% and the corresponding load-deformation graphs are digitally plotted. It is observed that the specimens are deformed laterally while loading but it regained its original position after releasing the load. No permanent deformations are observed on the isolator specimen during the post-loading phase. Load-deformation graph for different layers of isolator specimen is shown in figure 7.


(a) (b)

**Figure 4:** *Compression test of isolator* **(a)** *Prepared specimen in UTM* **(b)** *Isolator under compression*

## 3 Results and Discussions

A controlled vertical displacement is given during the test. On loading the rubber above 50% vertical displacement, it is observed that the reclaimed rubber bulges out and taking up more load without any failure. But, after releasing the load, the reclaimed rubber sample regained its original shape. The same behaviour is observed for reclaimed rubber with CFRP reinforcement, but the lateral bulging of rubber is limited. During the initial stages, the load taken by the specimen is observed to be at a slow rate. After the initial compression of the pads, the load gradually increases, and all the specimens took up load almost in the same range. This is in contrast to the case of scrap tyre pad isolators, for which a definite failure mode is observed which is marked by the failure of steel strands [8]. Condition of isolator specimen during and after applying the load is shown in figure 5.



(a) (b)

**Figure 5:** *Isolator specimen* **(a)** *during and* **(b)** *after applying load*



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The load-deformation curve from compression test gives an idea about the load carrying capacity of the specimen. Load carrying capacity of the samples are found out corresponding to 50% deformation and is tabulated in table 2. The load-deformation curves of all specimens are identical to the load-deformation behaviour of hardened springs. The average vertical stiffness is computed as the slope of straight portion of the load-deformation curve obtained from compression test. Thus, the vertical stiffness computed for sample 3B (slope of dashed line) is shown in figure 6. The vertical stiffness for sample 3B is obtained as 17774.68 N/mm. Vertical stiffness of remaining samples are shown in table 2. From table 2, it can be observed that the vertical stiffness of samples with CFRP reinforcement is higher than that of samples without CFRP reinforcement.

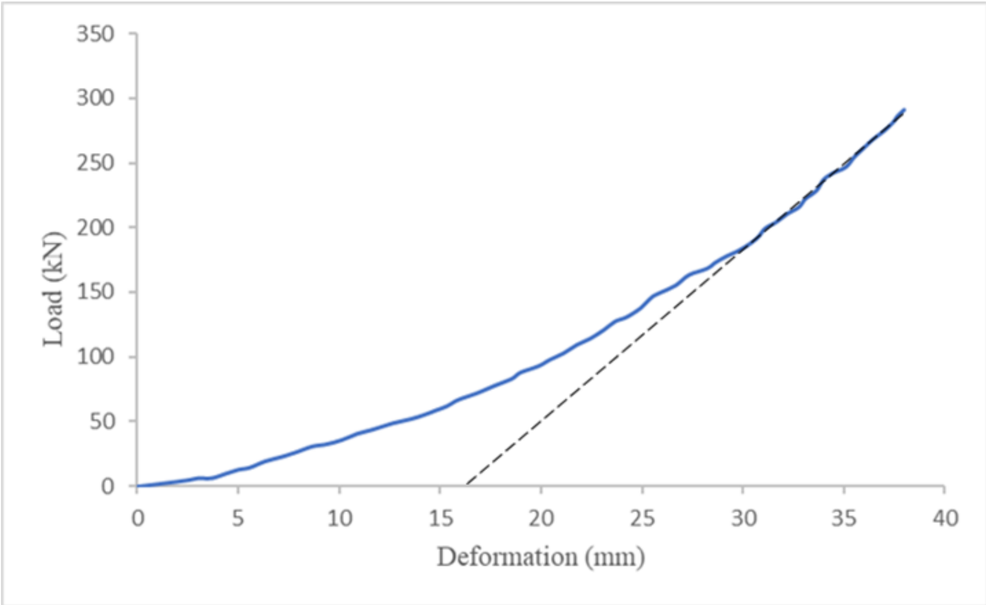


**Figure 6:** *Vertical stiffness from load-deformation curve*

Load-deformation curves all samples without CFRP and with CFRP reinforcement is shown in figure 7. It can be observed that, the vertical stiffness reduced as the number of layers increases. i.e., the vertical stiffness increases with an increase in aspect ratio. The variation of vertical stiffness with aspect ratio for samples with and without reinforcement are shown in figure 8.

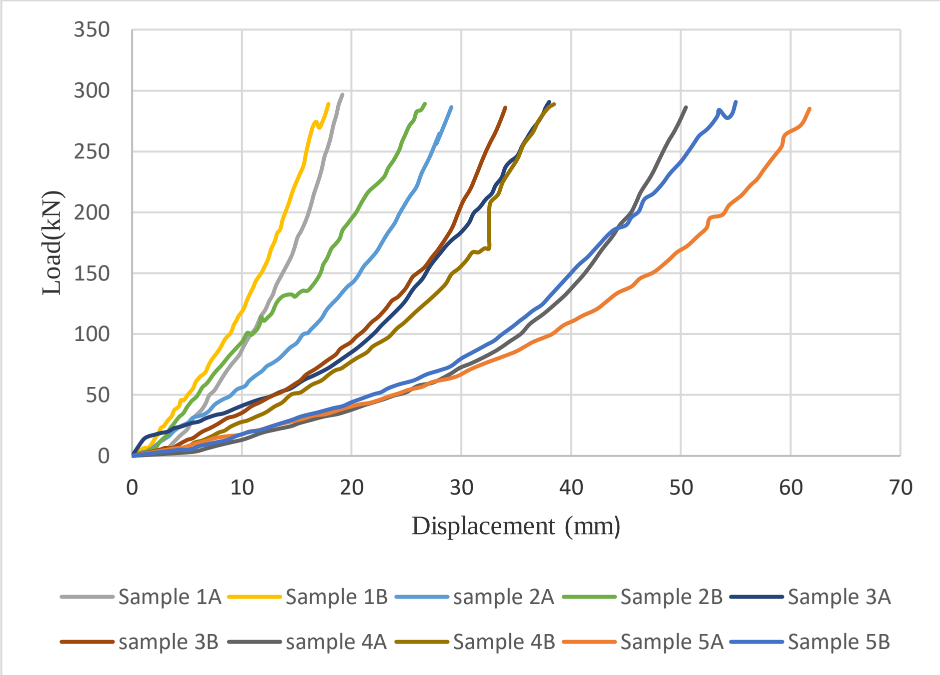


**Figure 7:** *Load-deformation curve for reclaimed rubber base isolator with and without CFRP reinforcement*

**Table 2:** *Compression properties of reclaimed rubber base isolator*

| | | | | | |
|---|---|---|---|---|---|
| Sample without reinforcement | 1A | 2A | 3A | 4A | 5A |
| Load corresponding to 50% deformation (kN) | 306.94 | 308.18 | 310.20 | 275.23 | 263.56 |
| Compressive strength (MPa) | 13.64 | 13.58 | 13.78 | 12.23 | 11.71 |
| Vertical stiffness (N/mm) | 18495.90 | 13660.71 | 10737.83 | 9596.37 | 6227.93 |
| Sample with CFRP reinforcement | 1B | 2B | 3B | 4B | 5B |
| Load corresponding to 50% deformation (kN) | 317.24 | 308.18 | 326.82 | 311.78 | 315.10 |
| Compressive strength (MPa) | 14.09 | 13.74 | 14.52 | 13.05 | 13.13 |
| Vertical stiffness (N/mm) | 24201.68 | 19002.06 | 17774.68 | 13978.43 | 9795.92 |

The load-carrying capacity of reclaimed rubber base isolator without reinforcement is found to be 11-14 MPa and that of base isolator with CFRP reinforcement is found to be in a range of 13 MPa for all the samples. Also, the vertical stiffness improved, and lateral bulging decreased when CFRP is used in between the layers. A higher load was taken up the rubber base isolator without any failure. The percentage increase in compressive strength and vertical stiffness of the reclaimed rubber base isolator is tabulated in table 3.

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**Table 3:** *Percentage increase in compressive strength and vertical stiffness*

| Number of layers | Compressive strength (MPa) | | Percentage increase in compressive strength | Vertical stiffness (N/mm) | | Percentage increase in vertical stiffness |
|---|---|---|---|---|---|---|
| | Without CFRP (A) | With CFRP(B) | | Without CFRP (A) | With CFRP (B) | |
| 4 | 13.64 | 14.09 | 3.30 | 18495.90 | 24201.68 | 30.85 |
| 6 | 13.58 | 13.74 | 1.17 | 13660.71 | 19002.06 | 39.10 |
| 8 | 13.78 | 14.52 | 5.37 | 10737.83 | 17774.68 | 65.53 |
| 10 | 12.23 | 13.05 | 6.70 | 9596.37 | 13978.43 | 45.66 |
| 12 | 11.71 | 13.13 | 12.12 | 6227.93 | 9795.92 | 57.30 |


**Figure 8:** *Variation of vertical stiffness with aspect ratio*

## 4 Conclusions

In this paper, an experimental study is done to estimate the load carrying capacity and vertical stiffness of reclaimed rubber base isolator with and without fiber reinforcement. The reclaimed rubber base isolator samples are loaded not more than 50% and all the samples sustained a load greater than 300 kN without any visible failure. On application of load, the reclaimed rubber base isolator started bulging out laterally without undergoing any failure. After removal of load, reclaimed rubber regained its original shape shows its ability to be reused. The load-carrying capacity of isolator specimen without reinforcement is found to be in the range 11-14 MPa and that of specimen with reinforcement is found to be in the range 13-15 MPa. The load-deformation curve for reclaimed rubber base isolator shows a behaviour similar to hardened spring. From the load-deformation curved it can be observed that the vertical stiffness of reclaimed rubber base isolator with CFRP reinforcement is higher than that of isolator without reinforcement. The reinforcement also reduced the lateral bulging of isolator. Also, the vertical stiffness decreased with the increase in number of layers.

From this, it can be concluded that enhancement of vertical stiffness and reduction lateral bulging of reclaimed rubber base isolator can be achieved by the introduction of fiber reinforcement in between the rubber layers. The vertical load carrying capacity will also be improved by using two or more layers of CFRP sheets in between the layers. In this study, one layer of CFRP sheets is incorporated. This study made an attempt to find the compression properties of reclaimed rubber base isolator experimentally. For the design of a base isolator other parameters like horizontal stiffness characteristics and energy dissipation characteristics also need to be investigated.

## 5 Publisher's Note

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## How to Cite

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