Civil Engineering and Architecture 12(3): 1516-1525, 2024 http://www.hrpub.org
DOI: 10.13189/cea.2024.120319

Experimental Investigation on the Evaluation of the Seismic Performance of Steel Frame with and without Sustainable STRP Bearings Subjected to Cyclic Loading

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Received October 18, 2023; Revised November 30, 2023; Accepted January 8, 2024

Cite This Paper in the Following Citation Styles

(a): *[1] Cici Jennifer Raj J., Venu Malagavelli, Srinivas Angadi, Selvaprakash S. , "Experimental Investigation on the Evaluation of the Seismic Performance of Steel Frame with and without Sustainable STRP Bearings Subjected to Cyclic Loading," Civil Engineering and Architecture, Vol. 12, No. 3, pp. 1516 - 1525, 2024. DOI: 10.13189/cea.2024.120319.*

(b): *Cici Jennifer Raj J., Venu Malagavelli, Srinivas Angadi, Selvaprakash S. (2024). Experimental Investigation on the Evaluation of the Seismic Performance of Steel Frame with and without Sustainable STRP Bearings Subjected to Cyclic Loading. Civil Engineering and Architecture, 12(3), 1516 - 1525. DOI: 10.13189/cea.2024.120319.*

Abstract The topic of the study looks at the performance of a steel frame under cyclic loads with a fixed base and a STRP base. Because of its effectiveness in resisting seismic shocks, seismic base isolation technology is thriving in industrialised countries. Scrap Tyre Rubber Pad (STRP) bearings will be a low-cost alternative to traditional seismic base isolation procedures for underdeveloped countries. The qualities of STRPs are nearly identical to those of traditional rubber bearings. Researchers conducted numerical analytical research on STRP bearing for buildings and proposed that it be employed for low-rise regular buildings, yielding superior results. In an effort to better understand how the STRPs operate in a scaled-down steel frame structure, an investigation has been made based on the findings of analytical investigations. The purpose of the experiment was to compare the steel frame's performance with and without STRP bearings. Examining the sliding ability of the STRPs positioned in the frame is the primary goal of this work. The deflections of the frame at the top, middle, and bottom stories have been evaluated for this aspect, for the lateral seismic force applied. From the investigation, it is observed that maximum deflections are observed at the roof storey than other stories tested for the investigation. Significantly, it is observed that an ultimate degradation of stiffness of the frame of about 23% to 40% is attained and subsequently, a superior increase in energy dissipation capacity of about 40% is attained which is a prominent factor required for a base isolation material.

Keywords STRP, Steel Frame, Cyclic Loading, Stiffness Degradation, Energy Dissipation Capacity

1. Introduction

Earthquakes are unpredictable events in which the design criteria or codes are being designed based on the past earthquake time history datum [1]. The codes are being revised based on the earthquakes which struck during that scenario. The revision of codes to meet the seismic demand increases the cost of construction ultimately. To avoid this issue, the concept of seismic isolation technologies is to be used to meet the required seismic demand to attain its capacity [2-4]. The ideology of seismic isolation was being applied since ancient times by the kings and emperors of various locations. Recently, this idea is becoming a popular technology which is being implemented in minimal aspect even in developed countries due to its cost factor and requirement of unskilled labors [5-6]. The affordability in implementing this technology shall be attained by the adoption of recyclable materials such as scrap tyres for seismic isolation [7-10]. These tyre scraps act as the excellent seismic isolator and have the properties quite relevant to conventional rubber bearings. Recently, researchers have started to undergone extensive research on this type of recyclable seismic isolation material to validate the performance and applicability to implement this material for base isolation [11-12].

An Elephant Foot seismic shock absorber, described in Saevfors' 2016 [13] proposal, is a base isolation technique. Large spherical stones are initially positioned on the ground in this technique. During the earthquake, these stones slide and roll like a roller. In addition to this setup, 'Elephant Foot', a scrap tyre put between the standard foundation and a concrete component weighing 20 to 40 kg—is added, as indicated in Figure 2. Additionally, the waste tyres serve as this isolation system's horizontal and vertical rigidity. Additionally, these kinds of isolation systems were used in poorer nations as a temporary seismic shock absorber. However, the author advised that more in-depth research be carried out and applied to all real-world situations.

The research focused on low-cost seismic isolation techniques using used vehicle tyres. For instance, many STRP specimens were constructed using a variety of layers and orientations. Additionally, the qualities of the STRP's are compared with those of conventional Bearings such High damping rubber bearings and Lead Rubber Bearings. The mechanical and dynamic properties of the specimens are tested experimentally and compared with the same. The authors came to the conclusion that there are significant parallels between this and the traditional bearings. Additionally, the authors claimed that STRP specimens eventually fail at 8.5 MPa when compressive stress is applied [14].

Cici Jennifer Raj and Vinod Kumar [15-18] used a popular technique called Fast Nonlinear Analysis to analyse the performance of STRP bearings installed in RC framed regular and irregular shaped structures. The scientists found that the experiment revealed a greater reduction in base shear, acceleration, and drift at the upper stories. Furthermore, the researchers discovered that STRP base solely resulted in increased storey displacements at the roof and, as a result, greater storey drifts.

Automobile radial tyres were used to create STRP samples, which were then adhered to nylon. For the developed specimens, the authors ran axial compression tests and horizontal shear tests. Then, characteristics like the damping factor and the horizontal and vertical rigidity were established. Additionally, the authors used ETABS Software to conduct an analytical investigation of an eight-story hospital building that is situated in seismic zone 3. The scientists came to the conclusion that radial tyre specimens have a larger damping ratio than natural rubber bearings. Additionally, the authors claimed that the installation of STRP specimens in the building reduced base shear by almost 50% [19].

The performance of three-storey building situated in Malaysia was investigated to evaluate the performance of with STRP bearings for base isolation. The STRP bearing was prepared with five layers. A compressive load of 380 kN was applied over the specimen and the authors reported that a deformation of 12.5 mm was observed [20].

Mishra et al. [21] have undergone experimental investigation on STRP bearings bonded and unbonded cases. From the vertical compressive loading applied, a maximum strain of about 150% is attained in bonded STRP than unbonded STRP bearings. Moreover, the authors also reported that lateral displacement is minimal in case of bonded STRP bearings than unbonded STRP bearings.

The researchers have extensively studied the mechanical properties of STRP bearings. Moreover, from the state of art, it is observed that, the studies were conducted with RCC structures but for steel building, it is required to be conducted, exclusively with STRP base. In this present research, the earthquake loading has been applied as the lateral cyclic loading on the frame and the corresponding deflections are measured at the top, middle and the storey connecting the STRP bearings. The basic requirement of an earthquake resistant structure/ building has the ability of dissipating earthquake energy efficiently and ultimately an anticipated reduction in stiffness. The decrease in stiffness significantly increases the time period and reduces the frequency. Therefore, the parameters such as energy dissipation capacity, cumulative energy dissipation capacity, stiffness degradation and cumulative stiffness degradation of the frame with and without STRP bearings were broadly investigated in this present research.

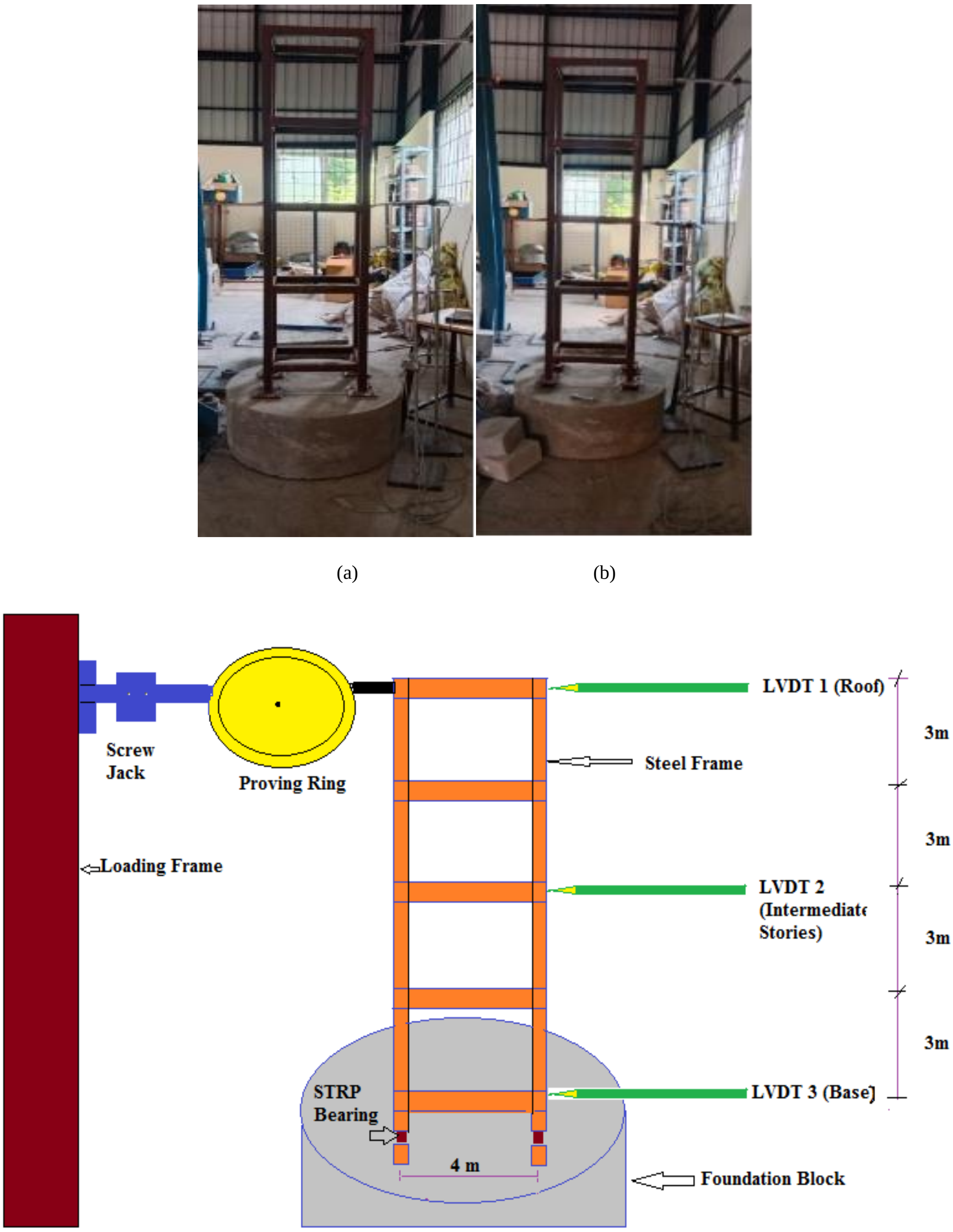
2. Methodology

The experimental investigation consists of four major protocols to be carried out. The steps are casting of the foundation block, preparing the steel space frame, Casting of STRP bearings. Once the above works have been conducted, the study shall be started. The rigidity of the steel frame is ensured by the connection of the frame with that of fixed base and here, the frame is to be fixed to the foundation block. The figure depicts the casting of a foundational block. The foundation's volume is 0.139 m^3, and its height and diameter are 0.305 m and 0.762 m, respectively. The concrete's grade is M 30 grade [22]. Cement, fine aggregate, coarse aggregate, and water were all used in the mix design, which was done in accordance with IS 10262:2016, and their respective weights were 94.85 kg, 79.037 kg, 153.14 kg, and 42.68 litres. The foundation has been cured for 28 days in order to prevent failure of the foundation block when lateral seismic force is applied. The foundation block serves as the steel frame's permanent basis to prevent excessive deflections during loadings.

In this paper, G+4 storey steel frame [23], scaled down to 1/10th has been used for the investigation. The structure is 1.45 m high, 0.6 m width and depth 0.3m. The steel plate is made up as per ASTM a- 36, which is EN S275 steel plate as per IS 2062:2011 code [24]. Figure 1a and Figure 1b show the steel frame with and without STRP bearings respectively with its schematic representation in Figure 1b. The frame has been casted based on the specifications given in Table 1.

Table 1. Specifications of the Steel Frame [23]

Parameters	Values
Yield Stress	250 MPa
Cross- sectional area of columns	243.84 mm^2
Cross- sectional area of beams along x-direction (T section)	660.67 mm^2
Cross- sectional area of beams along y-direction (Rectangular section)	303.30 mm^2



(a) (b)

(c)

Figure 1. Steel Frame (a) Fixed Base (b) STRP Base(c) Schematic Setup of the Frame

2.1. Casting of the Foundation Block

In the second phase of the research, a foundation block has been casted as shown in the Figure 2. The grade of the concrete used is M 30 grade [22], volume of the foundation is 0.139 m^3, height and the diameter of the foundation block are 0.305 m and 0.762 m, respectively. The mix design has been conducted as per IS 10262:2016 and the quantity of the ingredients such as cement, fine aggregate, coarse aggregate and water arrived as m 94.85 kg, 79.037 kg, 153.14 kg and 42.68 litres respectively. The foundation has been cured for 28 days so that when lateral seismic loading is applied, failure of the foundation block is neglected. The foundation block act as the fixed base for the steel frame to prevent excessive deflections in the frame during loadings.

(a) (b)

(c) (d)

Figure 2. Foundation Block Casting (a)Initial Mound Preparation (b) Mixing of Concrete (c)Filling of Mould with Concrete (d) Completed Foundation Block

2.2. Preparation of STRP Bearing

Scrap tyres are obtained from the landfills of Avadi town, Chennai. The selection of the tyres for the preparation STRP bearings is automobile truck/ bus tyres. The tread part of the tyre has been used for the preparation of STRP bearings as shown in Figure 3. As proposed by the researchers, the appropriate dimensions are taken and prepared as shown in Figure 3. In this current research, the bearings are scaled to accommodate the frame. The tyre scraps are cut in suitable sizes and arranged in 6 layers and packed together using adhesives. The design of the STRP bearings is to be carried out as per UBC-97 design principles [24-25] and the size of the bearing used is 200 mm x 180 mm x 46 mm [26]. Most exclusively, the dynamic properties are satisfactory as analysed and reported by the previous research [27-28] and it is to note that these types of bearings shall be utilised in high seismic risk zone but restricted to 19.2 m as per ASCE-7-05 code conditions [29-30]. The efficiency of STRP bearings is tested analytically and therefore the bearings are to be tested experimentally.

(a) (b)

Figure 3. Scrap Tyres (a) STRP Used for the Investigation (b) Preparation of STRP's

2.3. Experimental Investigation

The steel frame is fixed to the foundation block with fixed base as shown in Figure 1a and STRP base as shown in Figure 1b. A 5-ton screw jack as shown in Figure 4a is used for the research. For the application of loads, proving ring of capacity 50 kN has been utilised for the research as shown in Figure 4b. LVDT's are placed at the top and the intermediate stories of the frame and are connected to data acquisition system as shown in the Figure 4c.

(a) (b)

(c) (d)

Figure 4. Equipments for the Study (a) Jack (b) Proving Ring (c) Data Acquisition System (DAS) (d) LVDT Connections to DAS

(a) (b)

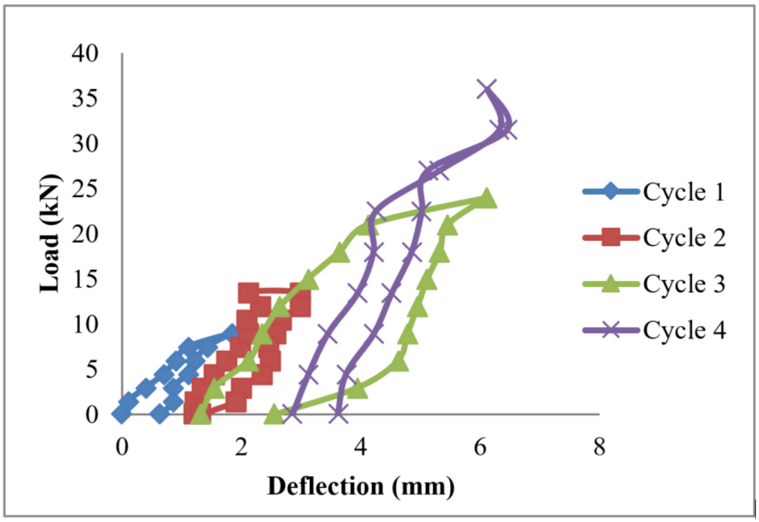
Figure 5. Experimental Setup (a) Frame connected with jack and proving ring (b) LVDT Placement

The LVDT's are connected to the data acquisition system as shown in Figure 5. The data acquisition system accurately read the values of deflections observed the frame at three different locations such as at the roof, intermediate and bottom storey. The jack is fixed firmly to the loading frame and extensively, the proving ring is connected and subsequently connected to the frame. Load is applied gradually from the screw jack and the corresponding deflections are measured in the LVDT's. As the capacity of the screw jack is 50 kN, load is limited to 40 kN. In the first series of test, the frame is of fixed base condition. Load is applied and the respective deflections are determined in the LVDT's. The respective load deflection graphs are plotted and shown in figure. For fixed condition. Subsequently, the STRP bearings are placed at the four bases of the frame as Load is applied using the screw jack and the corresponding deflections are measured in the LVDT's.

3. Results and Discussions

3.1. Cyclic Loading

The Load is applied on the frame based on the capacity of the proving ring which is 50 kN. The deflections pertaining to the load applied at the roof with the increment of 3 kN has been recorded. The deflections at the levels such as opposite side of the roof, intermediate storey and at the bottom storey were recorded. For instance, for 35 kN load, the deflection levels-were varying with minimal account. At 35 kN load, in case of fixed base, deflection at the roof, intermediate storey and at the base is arrived to be 3.25 mm, 2.88 mm and 2.6 mm respectively. Subsequently, at 35 kN load, in case of STRP base, deflection at the roof, intermediate storey and at the base is determined as 3.76 mm, 3.21 mm and 3.10 mm respectively. From the results as pictorially shown in Figure 6, it is observed that maximum deflections are attained with STRP base compared to top fixed base in all the stories considered. The base isolators have the capacity to slide to and fro due to its sliding property during the seismic action and therefore, the deflections are higher and the similar criteria have been attained [31]. Comparatively, the deflections of the fixed base are minimal compared to STRP base. In addition, the deflections at the roof are higher compared to other stories which is attained in both fixed and STRP base and the results are related with previous studies. The cyclic loading has been applied in four different cycles with the increment of 3 kN and the load Vs deflection plot is drawn for instance. From Figure 6 and Figure 7, the stiffness degradation ranges and the energy dissipation capacity of the frame are evaluated.



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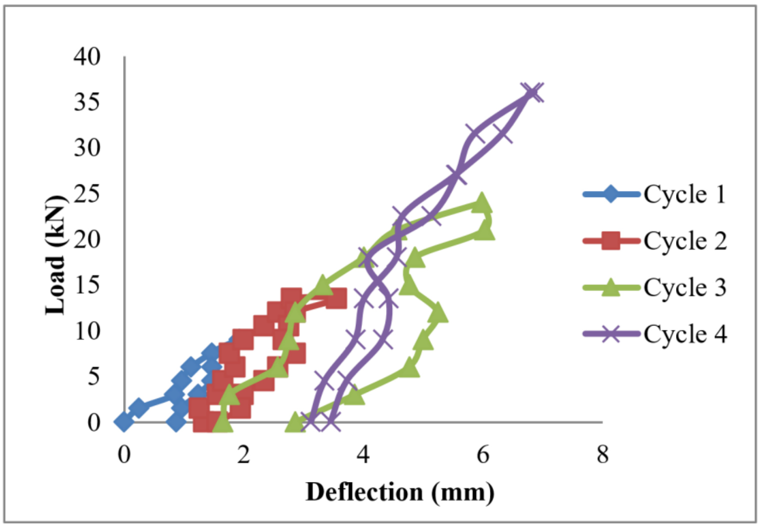

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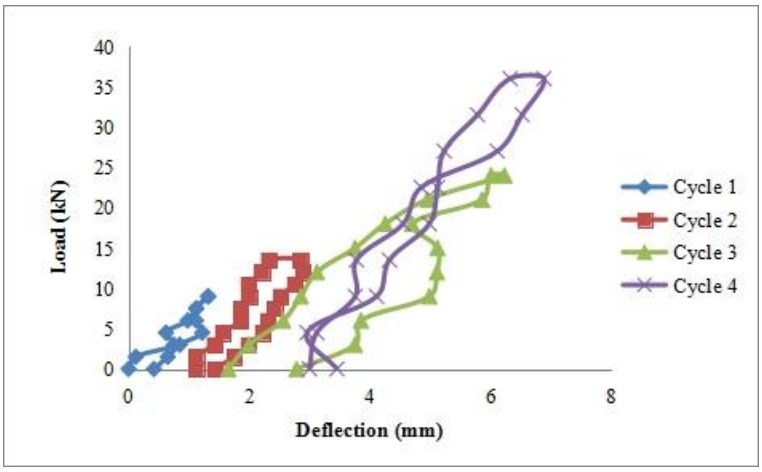
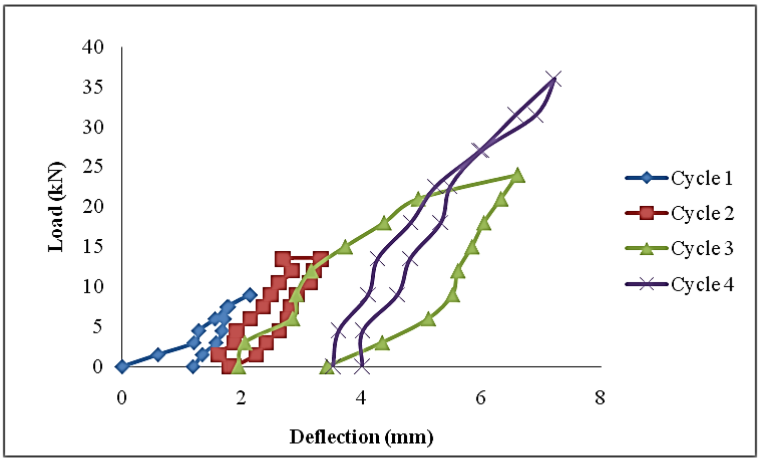


(c)

Figure 6. Cyclic Loading applied on the Steel Fram for Fixed Base (a) LVDT at the Roof (a) LVDT at the Intermediate Storey (c) (a) LVDT at the Bottom Storey



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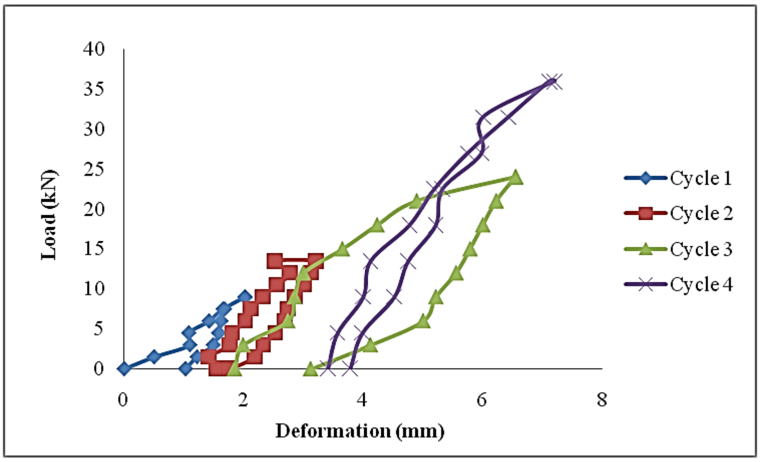

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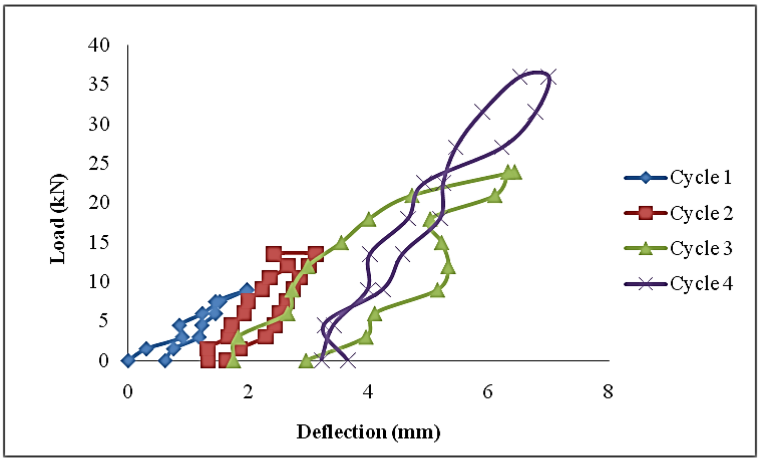

c)

Figure 7. Cyclic Loading applied on the Steel Fram for STRP Base (a) LVDT at the Roof (a) LVDT at the Intermediate Storey (c) (a) LVDT at the Bottom Storey

3.1.1. Stiffness Degradation

The degradation in stiffness ultimately increases the fundamental period of the building as shown in Figure 8, which is the required aspect in seismic engineering. Stiffness is the load needed to produce unit deformation. A tangent is drawn over the cyclic graph and the value of the stiffness is generated for both fixed and STRP base. At the beginning in the first cycle the cumulative stiffness degradation is 15% reduced with STRP base than fixed base. Furthermore, at the end in the fourth cycle, a significant reduction in stiffness of about 23% is attained using STRP base compared to fixed base. The degradation in stiffness ultimately increases the time period, decreases the fundamental period and therefore, the structure is flexible to the seismic forces and the frame which has been tested in this present research also attains similar results [32, 33]. Base isolators-reduce the stiffness by the ability of the isolators to slide to and fro during the earthquake. The greater flexibility and reduced stiffness are attained. Similar property is being absorbed in STRP base isolator which has excellent degradation in stiffness compared to fixed base [16, 34-35].

3.1.2. Energy Dissipation Capacity

The very significant factor to be dealt is the phenomenon of energy dissipation capacity in the field of base isolation. The increased energy dissipation capacity indicates that t the isolator has the capacity of dissipating the seismic energy effectively.

Initially, the cumulative energy dissipation capacity is about 31% greater with STRP base compared to fixed base. At the end of the fourth cycle, energy dissipation capacity is 101% greater with STRP base than fixed base. The reduction in fundamental frequency reduces the stiffness of the frame and ultimately the energy dissipation capacity increases significantly which the prominent aspect is observed in this research [32, 36] and is pictorially shown in Figure 9.

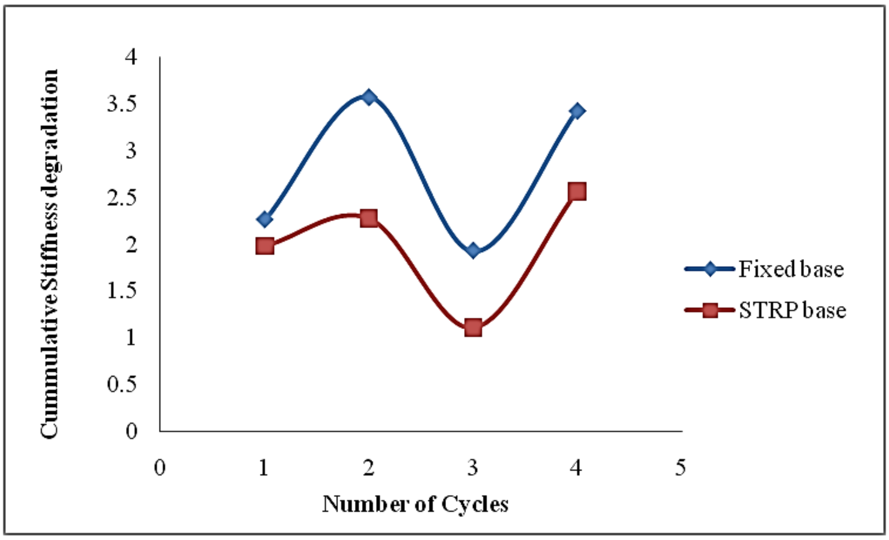

Figure 8. Energy Dissipation Capacity of the Frame for Fixed and STRP Base

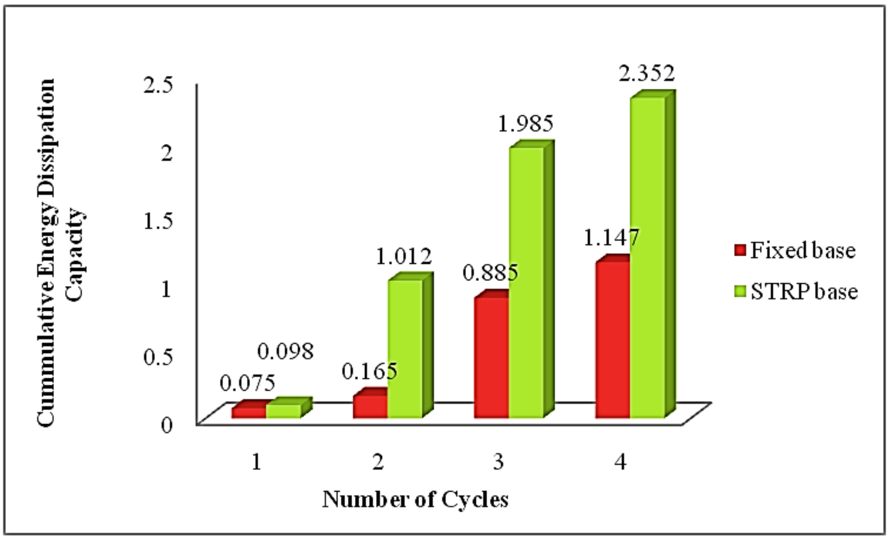

Figure 9. Stiffness Degradation of the Frame for Fixed and STRP Base

4. Conclusions

In order to establish seismic isolation in an environmentally sustainable way, the usage of recyclable tyre bearing (STRP) could be quite important. The goal of the modern world is to decrease the effects of seismic disasters, no matter the cost. For a developing country to apply, traditional base isolation techniques are more expensive and complicated. As a result, the alternative method of using STRP bearings shall efficiently and affordably reduce the seismic vibration.

The study shall be exclusively elongated and broadly investigated by reducing the scale of the frame model. Furthermore, in this study, the investigation pertaining to the lateral load applied from the left (one side) and deflections from the right. The performance of the frame with the load applied from opposite side (with corresponding deflections) is to be investigated.

From the investigation, the following conclusions were drawn:

- It is observed that an increase in storey displacement of about 10% to 25% is obtained with STRP base compared to fixed base.
- The degradation of stiffness with about 1.23 times to 1.65 times greater is attained with STRP base compared to fixed base.
- The dissipation of energy with STRP base as the isolator is about 1.13 times to 1.4 times greater is attained with STRP base compared to fixed base.

Abbreviations

STRP- Scrap Tyre Rubber Pad
LVDT- Linear Variable Differential Transformer
DAS- Data Acquisition System

Consent for Publication

The authors declare that there is no conflict of interest.

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