Evaluation of Vertical Stiffness of Scrap Tyre Pad Base Isolator with Change in Aspect Ratio

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ABSTRACT

Earthquake has severe effect on all kinds of structures. Usually, seismic isolation is done in case of high-rise buildings. But from the past experiences it can be observed that the effect of earthquake is not only restricted to high rise framed structures, but also to the low rise unreinforced masonry structures. In developing nations, it is very expensive to finance earthquake isolation measures to safeguard buildings which are not classified as important buildings, such as houses or other minor structures, making the adoption of this type of system almost unfeasible. By incorporating low horizontal stiffness devices into the structure, it is possible to reduce the impact of seismic loads on those structures. The elastomeric bearings, sliding bearings and hybrid systems are the most commonly used type of base isolators. Due to the presence of synthetic or natural rubber and high strength reinforcing cords, the Scrap Tyre Pad (STPs) exhibits substantial vertical stiffness and horizontal flexibility. Hence it can be used as a suitable seismic isolation material for structures. In the present study, experimental evaluation of variation of vertical stiffness of STPs is conducted and an empirical modal relating the percentage increase in stiffness to percentage increase in aspect ratio is proposed.

Keywords: Vertical Stiffness, Scrap tyre pad (STP), Seismic isolation material

1 Introduction

Seismic base isolation is the process of creating a laterally flexible system between the ground and a structure in order to increase the structure's natural period and minimize seismic pressures brought on by earthquakes. Recent earthquakes have shown that unreinforced masonry structures are extremely vulnerable. In the event of moderate to strong earthquakes, the lack of ductility and poor out-of-plane behaviour of the load bearing walls of these types of buildings causes considerable damage or entire collapse, which results in a significant loss of life. and properties. However, because of their increased durability and superior thermal insulation, this type of structure with thick walls is extremely common in various areas of the world. The development of novel, affordable, sustainable solutions is thus required to increase earthquake resistance and resilience. In general, base isolation systems extend the isolated systems natural periods and improve their damping to minimize the propagation of ground motion to the superstructure. With its great vertical rigidity and horizontal flexibility, the scrap tyre pad (STP), which is made of natural or synthetic rubber and high strength reinforcing cords it can be used as a seismic isolator for structures. The study focuses on the development of low-cost seismic isolation to reduce its vulnerability in case of common masonry buildings. For achieving the goal, a experimental study to analyse the variation of vertical stiffness with change in number of layers is done.

When compared to a fixed one, the base isolation system can significantly extend the life of the structure and minimize base shear by up to 75%. Steel-reinforced elastomeric isolators (SREI), despite being the most popular, are only employed in extremely big, expensive, and complex buildings because of their high production costs caused by labor-intensive manufacturing and vulcanization operations [1]–[3]. The finite element method can be used to analyse the characteristics of steel-rubber base isolators under combined

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axial tension or compression and base shear. For base isolators subject to a 375% shear strain, the impact of the axial load's magnitude and direction is examined [4], [5]. The investigation of the potential use of recycled car tyres for seismic isolation of structures and analyzed the special properties of tyre material where discussed in [6]. The performance of a three-story shear structure that is isolated at the base with scrap tyre pad (STP) bearings has been studied and examined [7]. This structure's response has been contrasted with another identical structure with a fixed base. Through the use of MATLAB, the natural frequencies and mode shapes have been calculated and contrasted. The results of the two cases demonstrated how powerful base isolation using STPs is in the fundamental mode of vibration.

For a base isolator the ratio of vertical stiffness to horizontal stiffness is an important parameter. The vertical stiffness of STPs varies with the aspect ratio. Aspect ratio is the ratio of top area by the lateral area which changes with change in number of layers. Hence to design the STP base isolator with respect to the required utility, the information's on effect of change in the vertical stiffness with number of layers is required to be determined. In the present study STP in unbonded configuration is used.

1.1 Specimen details

The tyres of standard size 185/65/R15 is used for study. The 185 represents the width in millimeters and the 65 represents aspect ratio of tyre, i.e., the ratio in percentage of side height to its width and 15 represents the inner circle diameter of the tyre in inches. The sample is made to the dimensions 145x145 mm size by means of water jet cutting. The average thickness of the selected sample is measured by using verneir calliper and known to be 9 mm. The figure 1 and figure 2 represents the top view and front view of the specimen respectively.

Figure 1: *Top view of specimen*

Figure 2: *Front view of specimen*

2 Methodology

The methodology followed on the study is illustrated in the figure 3. From the literature study it is understood that a low cost base isolation by STPs can be employed as an effective method in controlling the effect of earthquake in superstructure. The details of the sample collected is as discussed in section 2. Due to the presence of steel strands the specimen has to be cutted by the means of waterjet cutting. To design an isolator, it is important to figure out the parameters like damping ratio, horizontal stiffness, and vertical stiffness with respect to change in isolator height. The effect of change in vertical stiffness with respect to change in number of layer, that is terms of aspect ratio is studied in the present study.

Experimental setup as discussed in section 4 is prepared and the testing is done with the samples. Thus, to analyse the influence of the required parameter compressive strength of the specimen is experimentally studied on the STPs. From the analysis load displacement plot for different aspect ratio is recorded and the behaviour is studied.

3 Experimental Setup

In a computer-controlled universal testing apparatus, compression tests on the isolator specimens were conducted (figure 4). Two steel plates are provided in the top and bottom of STPs to uniformly distribute the applied load. The scrap tyre pads, which were initially somewhat convex in shape, were flattened during the post-loading phase. The specimen was loaded up until it reached about 300 KN of force. After each trial, specimens where replaced by new set of specimens The corresponding load and deformation were digitally recorded in computer by means of a software by Fuel Instruments and Engineers Pvt Ltd. The load displacement graph from the setup is obtained as shown in figure 5.

Selection of suitable sample size
↓
Collection of Scrap Tyre Samples
↓
Water jet cutting of tyres
↓
Preparation of the experimental setup
↓
Conducting the test with change in number of layer
↓
Analysis of result

Figure 3: *Methodology of the study*

Figure 4: *Experimental setup*

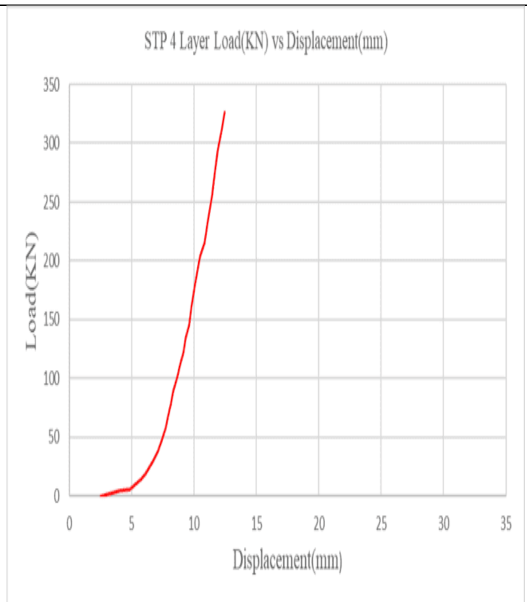

Figure 5: *Load vs displacement plot*

The aspect ratio of the isolator depends on the height of the isolator specimen; hence the plan area of the considered specimen is kept constant. The height of the specimen can be increased by increasing the no.

of layers. The number of layers of the considered samples and the corresponding aspect ratio is shown in the table 1.

Table 1: *No of layers and aspect ratio of sample*

Sample	No of Layer	Aspect ratio
1	4	4.023
2	6	2.685
3	8	2.014
4	10	1.611
5	12	1.342

4 Results and Discussion

The experiment is successfully completed by using the experimental setup mentioned in the Section 3. The STPs in unbonded conditions with 4 layer, 6 layer, 8 layer, 10 layer and 12 layer is used. The results from the experiment are discussed in detail in the following sections and an empirical expression to represent the influence of aspect ratio on stiffness is also discussed.

4.1 Effect of load on vertical stiffness

Figure 6 represents the load vs displacement characteristics of 4 layer, 6 layer, 8 layer, 10 layer and 12 layer samples. We can infer that the stiffness value is low in the initial stage before the application of load which is due to the initial curved shape of the tyre pads. It is also observed that after a certain loading the stiffness of the isolator is improved considerably in all cases under consideration. The slope of the curves seen decreasing with increase in number of layers. No breakage or failure is obtained in the specimen till 300 KN. The 4 Layer sample had the highest slope which shows that the isolator had behaved rigidly.

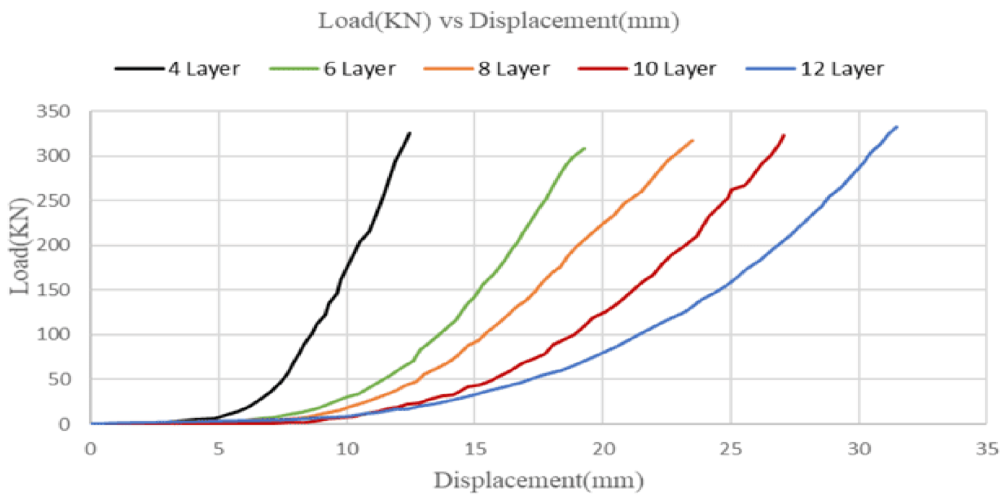

Figure 6: *Load vs displacement*

4.2 Effect of aspect ratio on vertical stiffness

The vertical stiffness can be calculated form the slope of the linear portion of the plot. The load displacement characteristics of 6 layer sample is as shown in figure 7.

$$\text{Stiffness, } K = \Delta F / \Delta l$$

where, ΔF = change in applied load and Δl is the change in displacement. Therefore, the stiffness value of 6 Layer isolators from the figure 7 is:

$$K = {}^{(302.093 - 156.28)}\!\Big/_{(18.7 - 15.33)}$$

$$K = 40.0345\ KN/mm$$

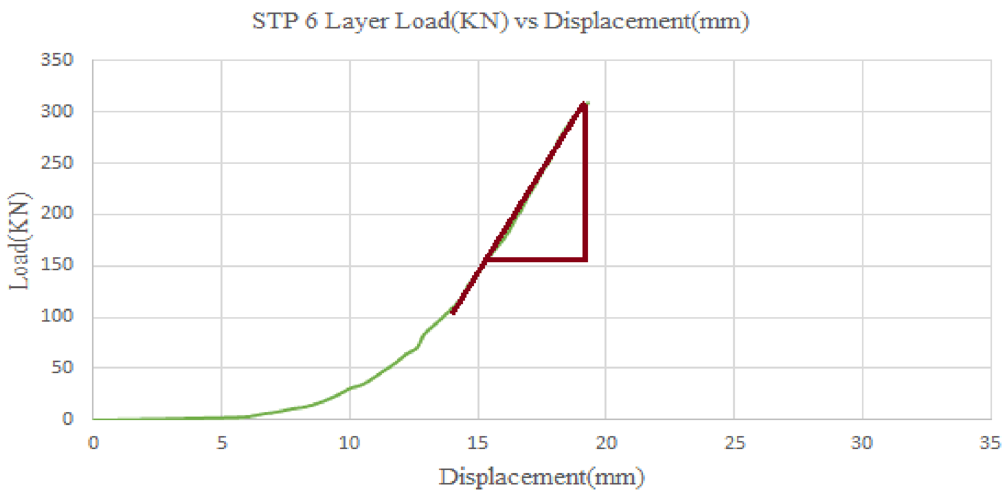

Figure 7: *Load displacement plot of 6 Layer specimen*

Table 2: *Vertical stiffness value of the different samples*

No of layer	Aspect ratio	Vertical Stiffness (KN/mm)
4	4.023	62.46
6	2.685	43.9
8	2.0139	38.01
10	1.611	33.76
12	1.342	29.07

The vertical stiffness with respect to aspect ratio which is obtained from the experiment is listed in the table 2. The figure 8 shows the no. of layer vs stiffness plot which represents that with increase in the no. of layers the stiffness value is increased. From the plot of aspect vs stiffness, the same observation is obtained that is increase in aspect ratio is proportional to the change in stiffness (figure 9). The change in behaviour of the stiffness is possibly due to the change in slenderness. However, the stiffness value is not linearly varying with respect to the aspect ratio. To understand the behaviour in detail an empirical relation is proposed between increase in aspect ratio and corresponding increase in vertical stiffness.

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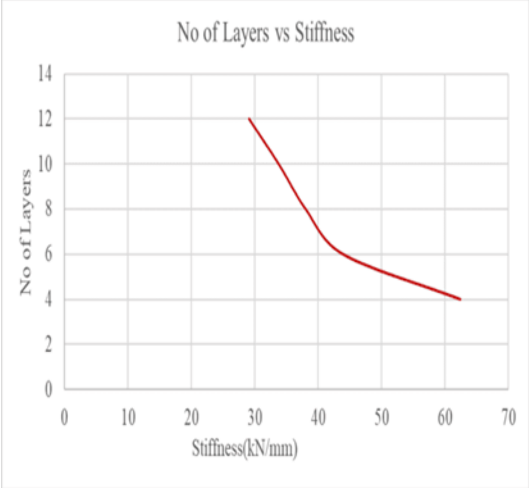

Figure 8: *No of layers vs stiffness plot*

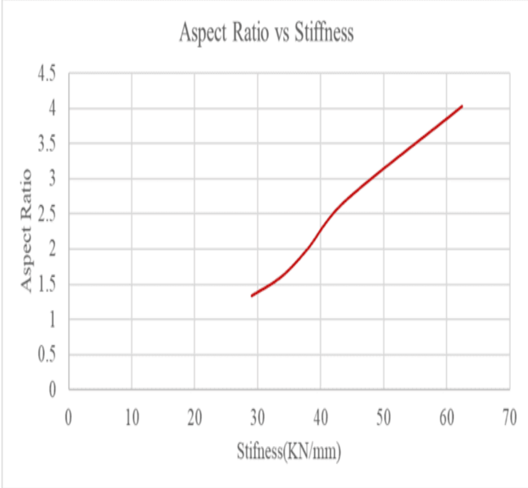

Figure 9: *Aspect ratio vs stiffness plot*

4.3 Empirical formulation

To study the influence of increase in aspect ratio with respect to the increase in stiffness a plot is generated between increase in aspect ratio to the corresponding increase in vertical stiffness as shown in figure 9. Even if the aspect ratio is increasing, the percentage increase in vertical stiffness with respect to the aspect ratio is less in the initial stage as shown in figure 10. By the analysis it can be inferred that instead of linear variation, the percentage increase in vertical stiffness followers a polynomial variation of third order. Thus, the variation can be represented as

$$y = ax^3 + bx^2 - cx + d$$

where, y and x represent the percentage increase in aspect ratio with the percentage increase in vertical stiffness respectively and a, b, c, d are constants having the values as -.0009, 0.1495, 6.0215, 84.028 respectively.

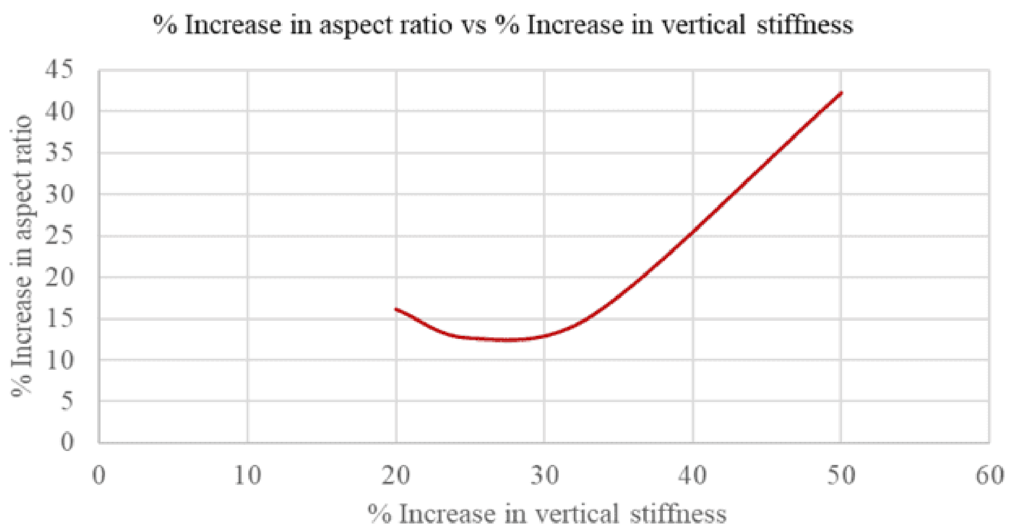

Figure 10: *% increase in aspect ratio vs % increase in vertical stiffness*

5 Conclusion

Experimental study on the unbonded scrap tyre pads are carried out to determine the effect of change in aspect ratio to the change in vertical stiffness. The conclusion from the study can be summarized as below.

- No failure is observed in the isolator when it is loaded until 300 KN.
- Aspect ratio is found to have considerable impact on the vertical stiffness.
- When the aspect ratio is less the scrap tyre pad performs more rigidly.
- The vertical stiffness is observed to increase with the increase in aspect ratio but the it is not a linear relationship.
- It is observed that the relation between percentage increase in aspect ratio and percentage increase in vertical stiffness follows a polynomial variation of third order.
- An empirical model relating percentage increase in aspect ratio and percentage increase in vertical stiffness is proposed.

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