INNOVATIVE BASE ISOLATORS FROM SCRAP TYRE RUBBER PADS

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ABSTRACT. Attenuating the effects of severe ground motions on buildings is always one of the most popular topics in structural engineering research. The reduction of seismic demand on structures can be achieved by providing certain degree of flexibility in the structure by installing the devices having low horizontal stiffness. Among these, elastomeric bearings, sliding bearings and hybrid systems are the most widely used. The introduction of flexible layer increases the deflection of the structure, thereby increasing the time period of the structure and decreasing the base shear. The Eco-friendly Scrap Tyre Rubber Pads (STRPs) provide several advantages such as low-cost, ease of handling and, simple shear stiffness adjustments, by changing the number of layers. They also provide environmental benefits, by recycling scrap tyres unlike other commercially available base isolators. In the present study, the properties of STRP specimen are evaluated experimentally. The STRPs are prepared by inserting layers of thin steel shims between rubber pads. Steel plates are provided at top and bottom and the entire assembly is subjected to vulcanization process. The tests conducted are (a) axial compression test and (b) horizontal shear test. Using the properties of STRPs obtained experimentally, a base-isolated G + 8 Reinforced Concrete (RC) building is analysed on software ETABS. It is found that there is considerable reduction in the base shear and storey drift by installation of STRPs. Hence the innovative base isolators from Scrap Tyre Rubber Pads can be used for low rise structures as base isolators.

Keywords: Base isolation, Scrap Tyre Rubber Pads, Elastomeric Isolators, Laminated Rubber Bearings

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INTRODUCTION

This paper focuses on the experimental and analytical studies conducted on the development of low-cost seismic isolation pads, using scrap automobile tyres. Seismic isolation is a well-defined building protection system against earthquakes. The majority of the previous studies focus on the performance improvement of the structure, when installed with base isolation systems. However, this study aims at cost and weight reduction of seismic isolation pads by recycling; otherwise useless material - scrap tyres. Elastomer-based isolators have been widely studied and used globally (Matsagar and Jangid) [3].

Steel or fiber reinforcement inside the elastomeric isolators provides high vertical stiffness, whereas rubber segments between reinforcement layers provide low horizontal stiffness. Automobile tyres have a similar effect as the steel plates or fibers inside the conventional elastomer-based isolators. Therefore, rectangular shaped layers cut from tread sections of used tyres and then piled on top of each other, can function as an elastomeric bearing. STRPs may be used as a low-cost alternative to conventional elastomeric bearings for seismic isolation of massive structures, masonry structures, pedestrian bridges, equipment isolation and such other applications.

LITERATURE REVIEW

Mishra and Igarashi (2012) [4] conducted experiments as well as analytical study on layer-bonded Scrap Tyre Rubber Pad (STRP) isolators to develop low-cost seismic isolators. The vertical compression and horizontal shear tests were conducted with varying axial loads and the test results were used to compute different mechanical properties of the STRP isolators, including vertical stiffness, horizontal stiffness and damping ratios. The tested STRP samples showed energy dissipation capacity considerably greater than the natural rubber bearings.

Turer and Ozden (2008) [5] conducted research to develop no-cost seismic base isolation pads using scrap automobile tyre pads. The mechanical and dynamic properties of STRP specimens made from different tyre brands, with different number of layers and orientations were evaluated experimentally. The results of these STRP tests were compared among themselves and against a commercially available Laminated Rubber Bearing (LRB) specimen. Static and dynamic tests conducted on STRP samples showed similarities between STRP and Lead Rubber Bearing (NZ - New Zealand) bearing and high-damping rubber bearing response.

SEISMIC ISOLATION

The seismic forces on the structures can be reduced if the fundamental period of the structure is lengthened or the energy dissipating capability is increased. Therefore, seismic isolation is a promising alternative for earthquake-resistant design of structures. Seismic isolation is essentially a method of controlling the seismic response of structures through yielding of the isolators, possessing generally bilinear force deformation relationship. Conceptually, seismic isolation decouples the structure from the horizontal components of the ground motion by interposing structural elements with low horizontal stiffness between the structure and the foundation. This gives the structure a fundamental frequency that is much lower than both; its fixed-base frequency and the predominant frequencies of the earthquake ground motion (Kelly, 1997) [2].

Elastomeric bearings consist of multiple layers of elastomer and steel shims, which carry gravity load of the superstructure and provide horizontal flexibility to reduce the level of seismic forces transmitted to the superstructure. The reason behind the popularity of the elastomeric bearings is the restoring force provided by the elastomeric material.

SCRAP TYRE RUBBER PADS (STRP)

The aim of the research is to develop low-cost isolation device for structural applications. To address this issue, the materials of the base isolation system should be easily available at an affordable cost. The rubber and the steel reinforcing wires used in manufacturing tyres are the alternative materials of the proposed isolation system. Usually, the Radial tyre contains steel reinforcing cords in the form of layers oriented in specified directions with respect to the Radial direction of tyre. The steel reinforcing wires are supposed to represent the steel plates used in conventional steel laminated elastomeric bearings, preventing the lateral bulging of the rubber bearings. In addition, these reinforcing cords are responsible to provide adequate vertical stiffness to the isolator. The purpose of the study is to check the feasibility of using the STRP as seismic isolator.

Objectives of Study

In the recent years, several practical techniques for achieving base isolation and a variety of energy dissipating devices have been developed and implemented around the world. Due to the size, weight and incurred cost of the available seismic isolation devices, the use of this technology is almost out of reach in the developing countries. This research work proposes an alternative seismic isolation system, particularly suitable for developing countries, making use of used tyre rubber. The primary objective of the research is to develop a base isolation system, which shall be effective in reducing the seismic demand on structures, made from easily available materials, at an affordable cost. Experimental investigations on specimen isolation bearings, in order to identify the behavior of the proposed seismic isolator with vertical compressive and cyclic shear loadings have been performed. The test results are used for numerical study of a five-storey Reinforced Concrete (RC) hospital building, to check the viability of the STRP.

Types of Tyres

Two types of tyres are available, viz. Nylon tyres and Radial tyres.

Nylon Tyres:

Nylon Tyres, also known as Cross Ply tyres, consist of layers made from Nylon cord. Cross Ply tyres provide a strong and rigid sidewall causing the tyre to overheat, when used on a hard road surface and thus causes the tyre to wear out quickly. Thus, these types of tyres are not suitable for trucks and buses.

Radial Tyres:

The Radial tyres consist of steel reinforcement vulcanized with rubber. The flexibility and the strength help the Radial tyres to absorb the impact shocks and the bumps, more effectively than the cross ply tyres. The vertical load carrying capacity of the isolators prepared from Nylon tyres is less, as compared to the Radial tyres, as the Radial tyres consist of steel mesh, which helps them to bear larger vertical loads.

Layer-Bonded STRP Specimen

Several samples of STRP and layer-bonded STRP bearings as shown in figure 1 were fabricated, for the purpose of vertical compression and shear loading tests. The specimen samples were prepared by using scrap bus / truck tyres. Square samples of size 150 mm and 200 mm were prepared. The number of strips to be used for the preparation of sample generally varies from a minimum of four to maximum of eight. More the number of strips, more flexible are the STRP bearings in horizontal direction; however, it results in the reduction in the stability of the samples. In this study, samples were prepared using four strips of tyres.

The layers were glued together for better bonding and to keep them intact and act like a single unit. Epoxy RB -106 was used as an adhesive. Adhesive (resin +hardener) was uniformly applied to each layer. In preparing the samples, thickness of each layer was 15 mm and thickness of applied epoxy layer was 2 mm. Using four such layers, the total thickness of the STRP was 66 mm. Two pieces of plywood, one above the sample and the other below the sample were placed to fix the C-clamp, to provide load on the sample for their proper bonding. The samples were then kept undisturbed for 7 days, as the epoxy requires 7 days for curing.

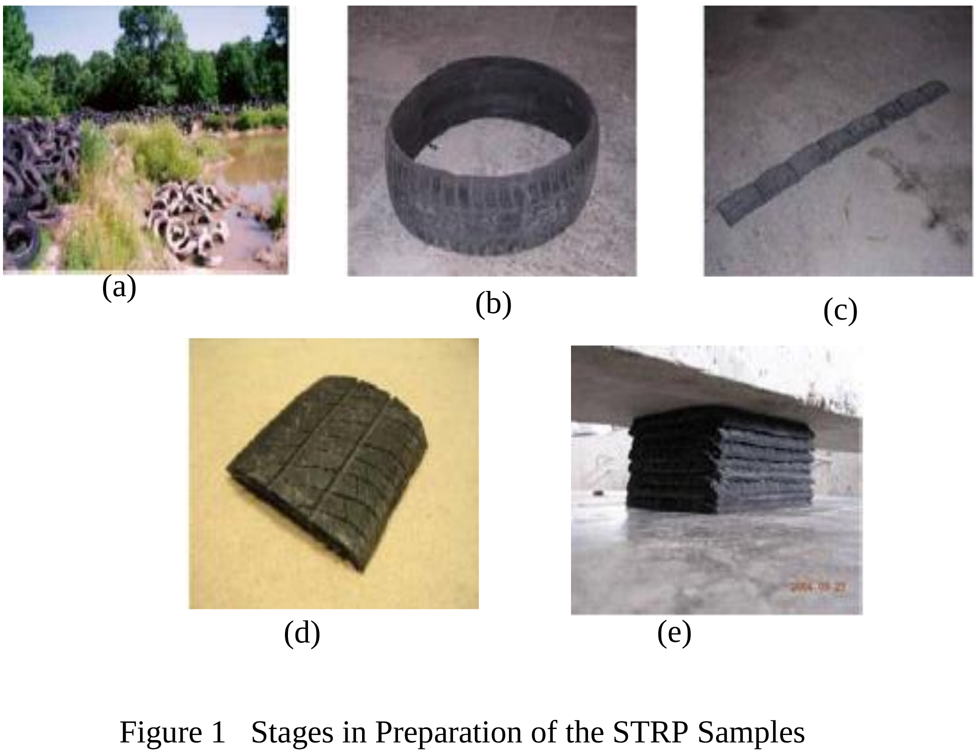

Figure 1   Stages in Preparation of the STRP Samples

EXPERIMENTAL STUDY ON THE LAYER-BONDED STRP SPECIMEN

Testing Machine

To investigate the properties of the layer bonded STRP samples, axial compression test and horizontal shear test were performed. The maximum vertical and horizontal load carrying capacity of the machine was 15,000 kN and 10,000 kN respectively. The standard stress to equivalent load conversion was 1 N/mm^2. Figure 2 shows the test setup.

Figure 2 Setup for Axial Compression Test

Axial Compression Test

In order to investigate the vertical load carrying capacity and vertical stiffness of the layer-bonded STRP, axial compression test was performed. Six samples of Nylon tyre and three samples of Radial tyre were tested. One sample from both types of tyres was tested to determine the maximum load carrying capacity until failure, initiated by severe cracking. Remaining samples were tested for cyclic vertical axial compression loading.

Testing and Analysis of Nylon Tyre Sample for Axial Compression

The first STRP Nylon tyre sample was tested for pure axial compression, in order to find the vertical load bearing capacity. It was placed between two steel plates, one above and the other at the bottom, for uniform application of load. Two dial gauges were placed in order to measure the vertical deformation of the sample. The deflection was measured at an equal load interval of 0.2 N/mm^2 until the sample failed. The failing of sample was noticed, as the sample was not able to carry any further load. The load factor applied as per the testing equipment was 1N/mm^2 = 363 kN. Maximum vertical load carrying capacity obtained was 363 kN. The load-deflection curve is as shown in figure 3.

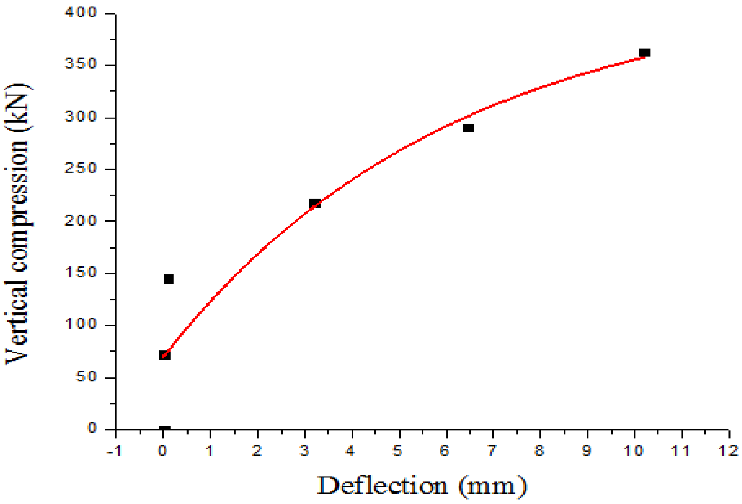

Figure 3 Deflection Against Vertical Compressive Load for Pure Axial Loading of Nylon Tyre Sample

TESTING AND ANALYSIS OF NYLON TYRE SAMPLE FOR VERTICAL STIFFNESS

Cyclic loading test was carried out on a Nylon tyre sample to find the vertical stiffness. The experimental setup was same as that for axial compression test. Two cycles of loading were applied on this sample. In the first cycle, the load was increased at equal intervals of $0.1 N/mm^2$, $0.2 N/mm^2$, $0.3 N/mm^2$ and $0.35 N/mm^2$. After applying the load of $0.35 N/mm^2$, the load was made zero. In the second cycle, the load was increased at equal intervals of 0.1 N/mm^2 up to 0.7 N/mm^2 and then it was further reduced to zero. The corresponding deformations were noted for both cycles. The cyclic variation of defection with vertical load, for a typical sample case is shown in figure 4.

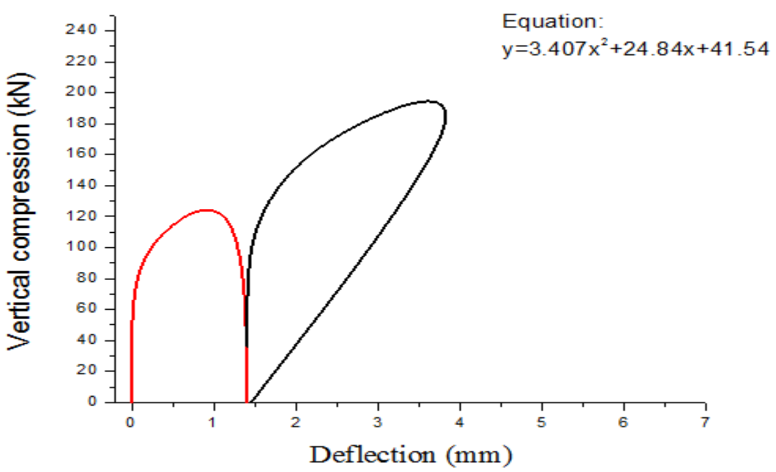

Figure 4 Cyclic Variation of Deflection for Nylon Tyre Sample

Equation of curve is

$$y = 3.407x^2 + 24.84x + 41.54$$

The vertical stiffness K_v is evaluated as $\frac{dy}{dx}$

$$\frac{dy}{dx} = 6.814x + 24.84$$

At $x = 1.37$mm (average deflection), $K_v = \frac{dy}{dx} = 34.16$ MN/m

Therefore, vertical stiffness of the Nylon tyre sample is 34.16 MN/m

TESTING AND ANALYSIS OF RADIAL TYRE SAMPLE FOR VERTICAL STIFFNESS

Maximum vertical load carrying capacity of Radial Tyres was obtained was 515.5 kN Cyclic loading test was carried out on this sample to find the vertical stiffness. In the first cycle load was increased at intervals of 0.1 N/mm^2 up to 0.35 N/mm^2 and the deflections corresponding to this incremental loading were noted down with the help of two dial gauges. After reaching to a load of 0.35 N/mm^2, load was removed. In the second cycle, load was increased at equal intervals of 0.1N/mm^2 up to 0.7N/mm^2 and then again reduced it to zero and; the corresponding deformations were noted. A typical load deflection curve for vertical deflection of Radial tyre STRP is shown in figure 5.

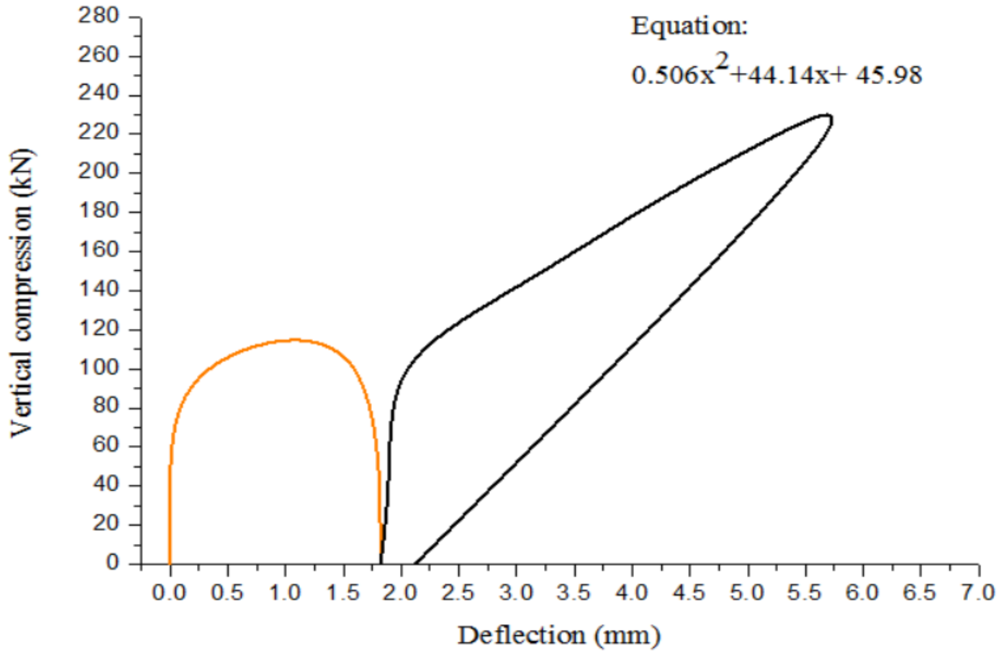

Figure 5 Cyclic Variation of Vertical Deflection for Radial Tyre Sample

Equation of curve is

$$y = 0.506x^2 + 44.14x + 45.98$$

$$K_v = \frac{dy}{dx} \ldots\ldots\ldots\ldots \text{ (}K_v\text{ indicates vertical stiffness)}$$

$$\frac{dy}{dx} = 1.102x + 44.14$$

At $x = 2.187$mm (average)

$$K_v = \frac{dy}{dx} = 46.35 \text{ MN/m}$$

Therefore, the vertical stiffness of the sample is 46.35 MN/m. Following the same procedure, two more samples were tested. The test results for Nylon and Radial tyres, tested in vertical cyclic loads are presented in Table 1. It presents vertical stiffness for Nylon and Radial tyre samples. The average vertical stiffness of Radial tyre STRP is found to be 1.45 times that of the Nylon tyre samples.

Table 1 Vertical Cyclic Load Test

Sr. No.	Tyre sample Type	Average vertical deflection (mm)	Vertical Stiffness (MN/m)
1	Nylon	1.37	34.16
2	Nylon	1.63	36.37
3	Nylon	1.72	27.16
4	Nylon	3.57	24.10
Average vertical stiffness of Nylon Tyres			30.5 MN/m
5	Radial	2.19	46.35
6	Radial	6.86	42.00
Average vertical stiffness of Radial Tyres			44.175 MN/m

HORIZONTAL SHEAR TEST

In order to investigate the horizontal load bearing capacity, horizontal stiffness and the damping ratio of layer-bonded STRP, horizontal shear tests on both type of samples i.e. Nylon tyre and Radial tyre were conducted. The testing was done on three pairs of samples for both the type of tyres. Out of three specimens, first sample was tested only to determine horizontal load bearing capacity. Other pairs of sample were tested to determine horizontal stiffness. Setup for horizontal testing is shown in figure 6.

Horizontal Shear Test on Nylon Tyre Sample Pair 1:

The first sample was tested in order to find its horizontal load bearing capacity. Two samples were placed between three steel plates as shown in the figure 6. A constant vertical force of 450kN was applied. The samples were then horizontally sheared by applying the horizontal load on the middle plate and the corresponding lateral displacements of the sample were noted. The horizontal load bearing capacity of the sample was found to be 1110.8 kN.

Horizontal Shear Test on Nylon Tyre Sample Pair2:

In the first cycle, the load was increased at equal intervals of 0.2N/mm2 up to 0.8 N/mm2 and the corresponding deformations were noted. After applying the load of 0.8N/mm2, the load was made zero. In the second cycle, the load was increased at equal intervals of 0.4N/mm2 up to 1.6N/mm2 and then again reduced to zero. The corresponding deformations were noted. Figure 7 shows variation of deflection with horizontal load for Nylon tyre sample.

Figure 6 Setup for Horizontal Shear Test on STRP

$$K_h = \frac{f(+)-f(-)}{\delta(+)-\delta(-)} = \frac{580.8-580.785}{11-10.83} = 89.64 \text{ kN/m}$$

where, f (+), f(-), δ(+), δ(-) are peak values of horizontal force and deflections respectively. Therefore the horizontal stiffness for this sample is 89.64 kN/m

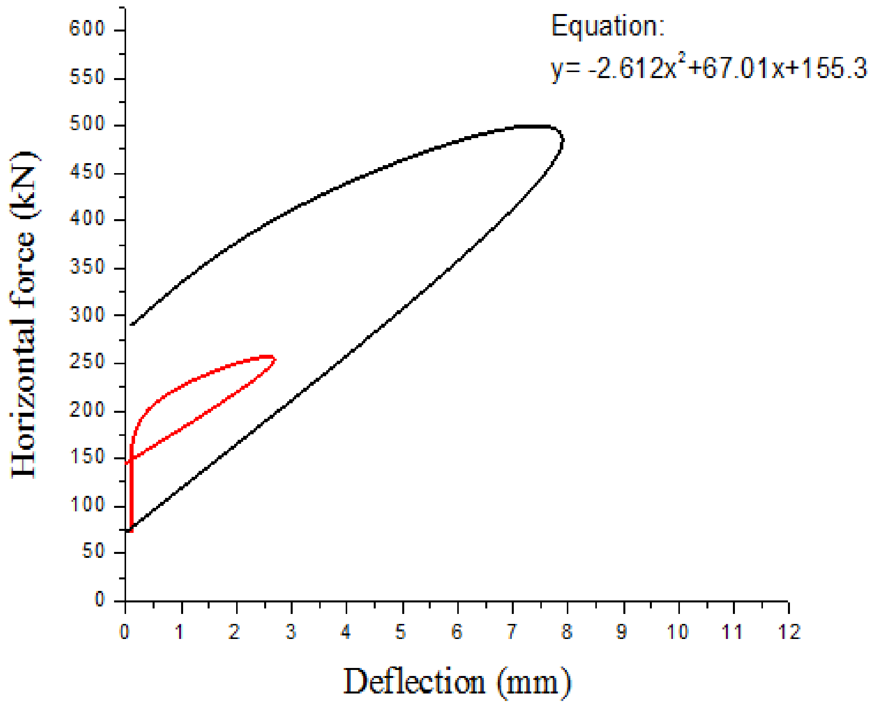

Figure 7 Deflection Against Horizontal Force for Cyclic Loading of Sample Pair 2 of Nylon Tyre

Horizontal Shear Test on Radial Tyre Sample Pair 1:

The first sample was tested in order to find its horizontal load bearing capacity. Two samples were placed between three steel plates as shown in the figure 6. A constant vertical force of 508 kN was applied. The samples were then horizontally sheared by applying the horizontal load on the middle plate and the corresponding lateral displacements of the sample were noted. The horizontal load bearing capacity of the sample was found to be 1216.04 kN.

Horizontal Shear Test on Radial Tyre Sample Pair 2:

In the first cycle, the load was increased at equal intervals of 0.3N/mm2 up to 1.2 N/mm2 and the corresponding deformations were noted. After applying the load of 1.2N/mm2, the load was made zero. In the second cycle, the load was increased at equal intervals of 0.4N/mm2 up to 1.6N/mm2 and then again reduced to zero. The corresponding deformations were noted. The horizontal load deflection curve obtained is shown in figure 8.

$$K_h = \frac{f(+)-f(-)}{\delta(+)-\delta(-)} = \frac{580.8-580.704}{1.4-0.639} = 126.15 \text{ kN/m}$$

where, f(+), f(-), δ(+), δ(-) are peak values of horizontal force and deflections respectively. Therefore, the horizontal stiffness for this sample is 126.15 kN/m.

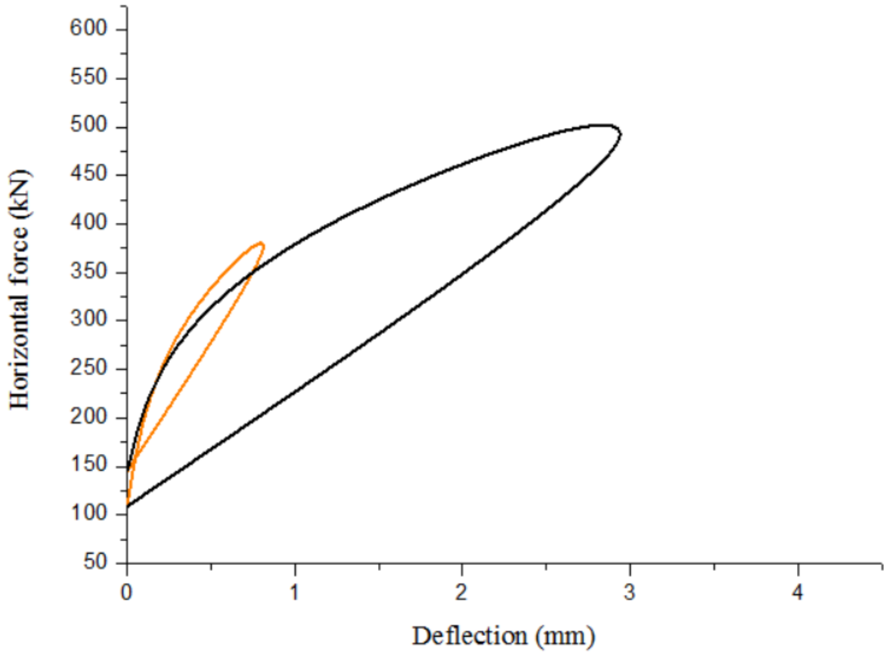

Figure 8 Deflection against Horizontal Force for Cyclic Loading of Radial Tyre Sample Pair

Table 2 Cyclic Loading Horizontal Shear Test

Sr. No.	Tyre sample Type	Horizontal Stiffness (Kh) (kN/m)	% Damping
1	Nylon	89.64	7.20
2	Nylon	96.04	7.63
3	Nylon	92.56	7.03
4	Nylon	98.16	7.91
Average horizontal stiffness of Nylon Tyres = 94.10 kN/m			
5	Radial	126.15	17.7
6	Radial	132.65	19.26
Average horizontal stiffness of Radial Tyres = 129.4 kN/m			
[illegible]			

Table 2 presents horizontal stiffness and damping values for Nylon and Radial tyre samples. Table 3 presents the ratio of vertical to horizontal stiffness for both types of tyres.

Table 3 Ratio of Vertical to Horizontal Stiffness of Tyres

Sr. No.	Tyre Sample	Kv (Average) (kN/m)	Kh (Average) (kN/m)	Ratio (Kv/ Kh)
1	Nylon	30,500	94.10	324.123
2	Radial	44,175	129.40	341.383

DAMPING RATIO (β)

The damping ratio was evaluated from the area under the curve, for each sample.

$$\beta = \frac{2}{\pi}\left[\frac{E_{loop}}{K_{eff}\{\delta(+)+(\delta(-)\}^2}\right]$$

where, δ(+), δ(-) are peak values of horizontal deflections.

Nylon Tyre Sample

The equation of curve for Nylon tyre sample from figure 7 is considered. The area under the curve is evaluated by integrating the equation of the curve between 0 to the maximum value of deflection. The horizontal stiffness is taken for sample 1, presented in table 2. Typical calculations for evaluating damping for both types of samples are presented below.

$$\text{Equation of curve} = -2.612x^2 + 67.01x + 155.3$$

$$E_{loop} = \int_0^{11}(-2.612x2 \ + \ 67.01x + \ 153.5)dx = 4603.545$$

$$\beta = \frac{2}{\pi}\left[\frac{4603.545}{89.64.\ \{11+10.32\}^2}\right] = 7.2\%$$

Radial Tyre Sample

$$\beta = \frac{2}{\pi}\left[\frac{E_{loop}}{K_{eff}\{\delta(+)+(\delta(-)\}^2}\right]$$

$$\text{Equation of curve} = -48.26x^2 + 297x + 160.1$$

$$Eloop = \int_0^{4}(-48.26x2 \ + \ 297x + \ 160.1)dx = 1988.053$$

$$\beta = \frac{2}{\pi}\left[\frac{1988.053}{126.15\ \{4+3.34\}^2}\right] = 17.7\%$$

ANALYSIS ON ETABS

An eight - storey hospital building located in seismic zone III was analysed on software ETABS, considering Importance factor 1.5 and Soil bearing capacity 300 kN/m2. The plan dimensions of the building were 54.931m × 38.404 m and the height of the building was 29.5 m, with floor-to-floor height of 3.5m. Figure 9 shows 3D model of the hospital building in ETABS.

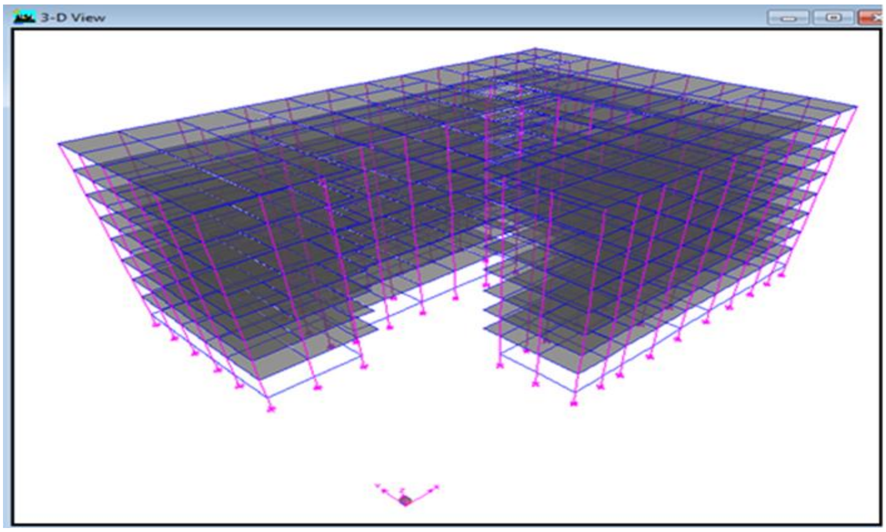

Figure 9 3 D Model of Hospital Building

The building was analyzed for two cases, (i) fixed base case and (ii) isolated base case. In the second case, properties of Radial tyre STRPs, evaluated experimentally, were used.

Table 4 Time Period and Spectral Acceleration of G + 8 RC Building

Mode	Time Period (sec) Without Isolator	$(Sa/g)_1$	Time Period (sec) With Isolator	$(Sa/g)_2$	% Difference
1	1.285	1.05	1.608	0.5295	49.57%
2	1.162	1.170	1.467	0.584	**50.08%**
3	1.115	1.219	1.377	0.6177	49.32%
4	0.424	2.50	0.471	1.576	36.96%
5	0.413	2.50	0.433	1.576	36.96%
6	0.375	2.50	0.426	1.576	36.96%
7	0.360	2.50	0.408	1.576	36.96%
8	0.300	2.50	0.322	1.576	36.96%

Using response spectrum method of analysis, the spectral acceleration for each mode was evaluated. Table 4 presents the time period and spectral acceleration values for first 8 modes of the building.

CONCLUSIONS

The time period for the building in all modes is found to increase after the installation of the Scrap Tyre Rubber Pads. This in turn decreased the value of Sa/g and thus reduced the value of Base Shear.

Maximum percentage difference for the spectral acceleration coefficient (Sa/g) between the time period without isolator and the time period with isolator is found to be 50.08 %. Average percentage difference for the spectral acceleration coefficient (Sa/g) between the time period without isolator and the time period with isolator is found to be 41.72%. As base shear is directly proportional to the spectral acceleration coefficient (Sa/g) as per IS 1893 part I (2002) clause 6.4.2, the value of base shear will reduce proportionally. Therefore, the installation of STRP isolators in the building has increased the time period and decreased the base shear to 50%, functioning like a conventional isolator. The minimum required ratio between vertical and horizontal stiffness is 150. Hence, the layer-bonded STRP bearings can be used for seismic isolation purpose

1. During the shear deformation, samples did not show layer separation. This indicates that the bonding agent is sufficiently strong in transmitting the shear forces.

2. The damping ratio of the tested STRP isolator made of Radial tyres (18.48%) is found to be greater than the damping ratio of the natural rubber bearings (3.5%). Therefore, the use of additional damping enhancement mechanisms can be avoided when using the STRP isolator for a specified level of damping.

3. Base shear force transmitted to the superstructure is reduced to 50% of that for the fixed base building. These results show that the base isolation system using STRP isolators is an attractive alternative to commercially available isolation systems.

4. The cost of one sample of Radial tyre (of dimensions 200 mm × 200 mm × 80 mm) works out to be Rs. 630/-, which is easily affordable, compared to the cost of conventional isolators.

5. The objective of making an isolator, which is easily reproducible, is also achieved, as the STRP requires no heavy machinery and no initial hefty investment.

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