Experimental and analytical studies on the compression properties of scrap tyre pad base isolators

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Abstract. Base isolation is one of the widely accepted seismic protection strategy. Scrap tyre pads have been identified to be suitable for the design of low-cost base isolation systems. The present study attempts to group scrap tyres of different brands based on their physical parameters and material properties. Five types of scrap tyres, from the same size group, have been identified in the present study. Tensile strength characteristics of scrap tyre pads were assessed by conducting experiments using ASTM D 638 specifications. The study investigates the compressive behaviour of seismic isolators made from different types of scrap tyre pads. Vertical stiffness and load bearing capacity of scrap tyre pad isolators were assessed for all the five types of scrap tyre pads. Three-dimensional finite element models of isolators were also developed and the response was found to be matching reasonably well with the experimentally observed response.

1. Introduction
Industrialization and urbanization of modern society has greatly increased the dependence on motor vehicles for various purposes. As a result, scrap tyre has become a major global environmental problem. The quantity of scrap tyre is increasing day by day due to its mismanagement and improper waste disposal systems. It is a challenging source of waste and its recycling is a tedious process as it is heavy, thick and made up of multiple materials. As it is non-biodegradable, tyres consume huge space in landfills. Also, water contamination occurs due to leaching of toxic substances from tyres as it contains heavy metals and other pollutants. Open burning of tyres creates thick black toxic smoke and large quantities of poisonous gas emissions. These emissions result in respiratory diseases and other health issues in living organisms.

The scrap tyre is proved to be a material that resists vibrations. In countries like China, scrap tyres filled with sand is used below the base of buildings as a method to arrest vibrations. It has been shown to be suitable for making seismic base isolators. Seismic base isolation is a passive structural vibration control strategy through which the structure is decoupled from ground motions and thereby restricts the transfer of earthquake forces in to the super structure during the time of an earthquake. This technology has not gained momentum in developing countries like India owing to its high cost. A simple and affordable seismic base isolation system using scrap tyre pads will be highly beneficial for
developing nations. The introduction of such a base isolation system will promote consumption of scrap tyres and hence reduce pollution due to its accumulation.

A low-cost base isolation system using scrap tyre pads has been proposed by Turer et al. [6]. Seismic isolators can be made by arranging scrap tyre pads one above the other similar to conventional isolators. It is identified that steel cord inside the scrap tyre is effective as steel plate in conventional elastomeric base isolators [6]. Application of glue between the tyre layers and use of nails and bolts enhances the stability of isolators [7]. The use of adhesive between tyre layers improves the contact force and thereby helps in controlling the ‘roll over deformation’ [3]. A comparative study of bonded and unbonded elastomeric isolators reveals that unbonded isolator is much better in dissipating energy when compared to bonded isolator [4]. Filling the vacant space between tyre layers with sand enhances the friction between the layers and thereby improves energy dissipation [5]. Tyre derived materials can also be used for seismic protection of buildings. Isolators made by using recycled rubber and polyurethane binder are found to be performing well in shake table test [2].

Even though, many researchers have come up with the idea of using scrap tyre pads as base isolators, none of the literatures specifies the required structural properties of scrap tyres for using it as an isolator. Scrap tyres are of different brands and are available in varying sizes. The structural properties of these tyres will be different for different brands. In order to design a seismic isolator for a specific structure using scrap tyre pads, the parameters of the scrap tyres need to be assessed. Compression properties such as stiffness and load bearing ability are significant for the design of base isolators. In this paper, scrap tyres have been graded based on the physical properties; and, structural parameters such as vertical load carrying capacity and vertical stiffness are assessed for each grade. The behaviour of base isolator made of scrap tyre pads is analysed using experimental and finite element procedures.

2. Basic strength properties
In general, tyres are made from styrene butadiene polymers and a small amount of natural rubber. In the manufacturing process of tyre, the raw materials are mixed according to the required performance. Tyre is a composite material which contains rubber, steel as well as textile. Tyres of different brands and sizes will have different properties. Also, the properties may vary with ageing because of its wear and tear. In order to identify the material properties, the collected scrap tyre samples were tested as per ASTM D 638 specifications. Scrap tyres of size 175/65 R14 were selected for the study. Here 175 and 65 represents the width of the contact patch and distance between the inner and outer circle of the tyre in millimetres.14 is the diameter of inner circle of the tyre in inches. For the same size, the number and arrangement of intervening steel cords are different for different brands. So, the scrap tyre samples were named as Type I, II, III, IV and V based on the number and arrangement of intervening steel cords and the classification is given in table 1.

| Sl. No | Name | No of strands | Spacing c/c (mm) |
|-------|------|---------------|-----------------|
| 1     | Type I | 3             | 1.25            |
| 2     | Type II| 2             | 1.00            |
| 3     | Type III| 2             | 0.75            |
| 4     | Type IV| 3             | 1.50            |
| 5     | Type V | 4             | 0.75            |

To conduct tension test on scrap tyre pads, dumbbell shaped specimens of shape and dimensions as specified in ASTM D 638 were cut from each scrap tyre. The shape and dimensions of the specimen are shown in figure 1 and table 2 respectively. The test was conducted in computer controlled
universal testing machine. The sample was supported with the help of jaws on top and bottom as shown in the figure 3. Two stage loading was implemented. Initially the strain was measured using an extensometer of gauge length 25 mm. After removing the extensometer, the tensile loading rate was maintained as 50 mm/min.

![Figure 1. Dimensions of specimen for tension test](image)

**Table 2: Dimensions of specimen-tension test**

| Label (Refer figure 1) | Dimensions [mm] |
|------------------------|-----------------|
| $W_c$—Width of specimen at narrow section | 19 |
| $L$—Length of narrow section | 57 |
| $W_O$—Width overall | 29 |
| $L_O$—Length overall | 246 |
| $G$—Gauge length | 50 |
| $D$—Distance between grips | 115 |
| $R$—Radius of fillet | 76 |

The specimen was loaded till failure and stress-strain plot is obtained. At the time of failure, steel cords separated out from the composite. It was observed that the failure occurred due to the separation of steel cords and not due to its breaking. For all specimens, stress-strain variation is found to be linear up to ultimate load. The stress-strain response of type I specimen is shown in figure 3.
Sudden failure is observed in the case of three types and the remaining specimens failed gradually. This variation in failure pattern is attributed to difference in number and arrangement of steel cords inside rubber and the extent of wear and tear of specimen. Table 3 shows the tensile strength and modulus of elasticity of various specimens.

**Table 3. Basic strength properties of scrap tyre pads**

| Sl. No | Name | Thickness (mm) | Average tensile strength (MPa) | Average modulus of elasticity (MPa) |
|--------|------|----------------|-------------------------------|-----------------------------------|
| 1      | Type I | 09.375         | 19.91                         | 37.99                             |
| 2      | Type II | 08.875         | 14.03                         | 34.67                             |
| 3      | Type III | 10.500        | 17.97                         | 42.34                             |
| 4      | Type IV | 09.250         | 12.06                         | 38.92                             |
| 5      | Type V  | 10.750         | 17.08                         | 26.77                             |
3. Experimental study on compression properties of scrap tyre pad isolators

3.1 Specimen preparation
Scrap tyres were cut into pads of dimension 150 mm x 150 mm which is the maximum possible dimension for the selected type of tyres. The curved portion near the end was avoided for better appearance. Five isolator samples were prepared, one from each type of scrap tyres, by arranging the pads in four layers. The thickness of layers is slightly different for each type of tyre and hence the total thickness of each isolator is different. Isolator samples were named as type I, II, III, IV and V based on the type of scrap tyre pad used for its preparation. One of the prepared samples is given in figure 4.

![Scrap tyre pad isolator specimen](image)

**Figure 4.** Scrap tyre pad isolator specimen

3.2 Compression test
The isolator specimens were tested under compression in a computer controlled universal testing machine (figure 5). The specimen was placed on the table of machine with two supporting plates on top and bottom of the isolator. The plates were provided to distribute the loads evenly along the surface of isolator. The specimen was loaded till failure under compression. During the initial phase of loading, the scrap tyre pads became flattened which were slightly curved in shape initially. The failure was identified by a sequence of snapping sounds and the corresponding load and deformation were noted. Even at this point, the isolator continued to resist much higher loads without any visible deformation. The load – displacement curves various isolators are shown in figure 6.

![Compression test of isolator](image)

**Figure 5.** Compression test of isolator (a) Isolator specimen in UTM (b) Enlarged view of specimen
3.3 Compression properties
From the compression test results, the vertical load carrying capacity was identified. It was found that all specimens are effective in resisting vertical loads. The slope of load-displacement curve gives the vertical stiffness of isolator. A bi-linear load-displacement response was observed for all samples as shown in figure 6. Tyre pads which are curved in shape flattened during initial part of loading and hence low stiffness is observed. In the next part of loading, stiffness increases slightly with increase in loading. The specimens fails due to breaking of steel cords, and the failure is marked by snapping sounds. Thereafter the specimen behaves as a rigid block. Even though specimens continued to carry larger loads without further deformation, the force at snapping sounds was accepted as the vertical load carrying capacity specimens.

The breaking load of type I,II ,III, IV and V specimens are 447.21 kN, 406.35 kN, 346.11 kN, 319.71 and 192 kN respectively. Also the vertical load carrying capacity was found to be over 8 MPa.

3.3.1. Evaluation of vertical stiffness. As the load-displacement curve is bi-linear, the stiffness will be different at different points of the load-displacement curve. The stiffness is very low during the initial part of loading, during which the pads flatten from the initial curved shape. Increased stiffness is observed after this phase and the specimen behaves as a rigid block after failure. Even though specimens continued to carry larger loads without further deformation, the force at snapping sounds was accepted as the vertical load carrying capacity specimens.

The load-displacement plot of scrap tyre pad isolators in compression resembles that of a hardening spring. It may be observed that the stiffness is varying with load/displacement. Hence, to estimate the
stiffness the working load need to be defined. In the present study, the working load is determined by dividing the breaking load by a factor of safety of two. Stiffness at the working load is adopted as the vertical stiffness of the isolator.

The figure 7 shows load displacement plot of type III specimen. The breaking load is observed to be 346.11kN. Applying factor of safety, working load is calculated as 173.05kN. The slope of tangent line at this point represents the average vertical stiffness of the isolator and it is found to be 68000 N/mm in the above case. Similarly, vertical stiffness values of all specimens were calculated and recorded in Table 4.

| Sl. No. | Type  | Dimensions | Breaking load (kN) | Maximum displacement (mm) | Compressive strength (MPa) | Vertical stiffness (N/mm) |
|--------|-------|------------|--------------------|---------------------------|---------------------------|--------------------------|
| 1      | Type I | 150×150×37.5 | 447.21             | 16.8                      | 19.88                     | 71428.57                |
| 2      | Type II | 150×150×35.5 | 406.35             | 13.5                      | 18.06                     | 69444.44                |
| 3      | Type III | 150×150×42  | 346.11             | 12.0                      | 15.38                     | 68000.00                |
| 4      | Type IV | 150×150×37  | 319.71             | 11.7                      | 14.21                     | 50000.00                |
| 5      | Type V  | 150×150×43  | 192.00             | 11.7                      | 8.53                      | 35714.20                |

The vertical load carrying capacity of scrap tyre pad isolators are found to be in the range of 8 MPa to 20 MPa. The vertical stiffness of isolators made from tyres of selected size and thickness varies between 35000 to 75000N/mm. The vertical stiffness values of Type II and type III specimens are nearly equal and both of these specimens contains same number of steel cords whereas vertical stiffness values of type I and type IV are not showing a similar trend even though both of these specimens contains same number of intervening steel cords. Also, type V specimen which contains large number of steel cords when compared to other grades shows very less values of vertical load carrying capacity and stiffness. The possible reason for this variation might be the difference in quality of rubber and extent of wear and tear.

4. Finite element analysis

A three-dimensional finite element analysis of different scrap tyre pad isolators was conducted in ANSYS V 19.1, general-purpose finite element software. Material constants used in the FEM analysis were derived from tension test of dumbbell shaped scrap tyre samples. A single layer of scrap tyre pad with dimensions 150mm ×150mm was modelled first and it was replicated to form a four layered scrap tyre pad isolator. The boundary condition was defined as fixed at the bottom face. The vertical load corresponding to experimental failure load was applied and the corresponding vertical deformation was compared with the experimental results. The displacement of the isolator corresponding to breaking load for all isolator samples is given in table 5. It may be observed that the FEM results are matching reasonably well with the experimental results, for all isolator samples.
Figure 8. Sample simulation output of scrap tyre pad isolator (a) Finite element model of scrap tyre pad isolator (b) Behaviour of isolator under compression load

Table 5. Comparison of experimental and analytical results

| Type   | Displacement at breaking load (Experimental) | Displacement at breaking load (ANSYS) |
|--------|---------------------------------------------|---------------------------------------|
| Type I | 16.8                                        | 16.63                                 |
| Type II| 13.5                                        | 14.33                                 |
| Type III| 12.0                                        | 14.56                                 |
| Type IV| 11.7                                        | 10.00                                 |
| Type V | 11.7                                        | 08.44                                 |

5. Conclusion
In the present investigation an attempt has been made to study the basic strength properties of scrap tyres with different physical properties. The compression test of scrap tyre pad isolators made from
scrap tyres of different grades was also conducted. Based on the limited study carried out, the following conclusions are drawn.

1. The tensile strength of scrap tyre pads is in the range of 10-25MPa and modulus of elasticity varies between 25-50MPa and the failure of specimen under tension occurred due to separation of steel cords. The strength of scrap tyre pad depends on the bond between steel cords and rubber.

2. The vertical load carrying capacities of selected type of scrap tyre pad samples are found to be in the range of 8 to 20 MPa. But the specimen is capable of resisting much higher loads even after the breaking point.

3. The load-displacement plot of scrap tyre pad isolator in compression is found to be bi-linear. The plot resembles that of a hardening spring.

4. The compression properties of scrap tyre pad isolator depends on the number of intervening steel cords, quality of rubber and also the extent of wear and tear.

The study conducted in the present work attempted to group scrap tyre pads based on the number and spacing of steel strands. The study provides insights into the compression properties of scrap tyre pad isolators. Design of isolator requires parameters like horizontal stiffness characteristics and energy dissipation characteristics too. The study along this direction is expected to provide useful inputs in the design of low-cost base isolation systems.

References
[1] ASTM D 638-03 code, Standard Test Method for Tensile Properties of Plastics, ASTM International, USA.
[2] Calabrese A., Spizzuoco M., Serino G., Corte G. D., Maddaloni G. (2014). Shaking table investigation of a novel, low-cost, base isolation technology using recycled rubber, Structural Control and Health Monitoring, 10: 1002-1017.
[3] Jie S. W., Tong S. Y., Kasa A., Osman S. A. (2016). Effect of recycle tire isolator as earthquake resistance system for low rise buildings in Malaysia, Journal of Engineering Science and Technology, 11: 1207–1220.
[4] Toopchi H., Nezhad Y, Michael J, Tait, Drysdale R. G. (2007). Testing and modeling of square carbon fiber-reinforced elastomeric seismic isolators, Structural Control And Health Monitoring,15: 876–900.
[5] Tsompanakis Y., Drosos P. P. V. (2011). Low-cost seismic base isolation using recycled tires cushions, 13th International conference on Civil,Structural and Environmental Engineering Computing, Chania,Crete,Greece September 6-9,2011.
[6] Turer A., Ozden B. (2007). Seismic base isolation using low-cost scrap tire pads (STP), Materials and Structures, 4: 891–908.
[7] Yamaguchi N., Narafu T., Turer A., Iiba M., Imai H. (2008). Shaking table test of simple and affordable seismic isolation, 14th World Conference on Earthquake Engineering, Beijing, China, October 12-17, 2008.