Seismic Performance of Multistoried Building Frames with Unbonded Scrap Tyre Pad Isolators

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ABSTRACT

Base isolation is one of the most powerful tools for earthquake protection of structures. The huge cost of conventional isolators makes them unaffordable for developing countries. The Scrap tyre pad isolator is an emerging low-cost technology for the seismic protection of structures. The tread portion of tyre can be cut into pads of definite size and arranged one above the other to form the isolator. In the present study, a G+7 storied structure isolated with scrap tyre pad isolators was analyzed using the response spectrum method in ETABS. The performance was also compared with that of conventional lead rubber bearings in terms of lateral displacement, drift ratio, storey accelerations, base shear and time period. The analysis results show that scrap tyre pad isolator is also effective in seismic protection of structures.

Keywords: Scrap tyre pad isolator, Framed structure, Response spectrum analysis

1 Introduction

Earthquake is one of the destructive natural hazards that cause a huge loss of life and property every year. Between 1990 and 2022, more than 300 earthquakes occurred in Asia alone [1]. On an average, earthquakes kill 20,000 persons per annum all around the world [2]. Even though earthquake threat is small when compared to other disasters like floods, droughts, hurricanes and wildfires, the recent catastrophic earthquakes remind the world community of the major threats that earthquakes pose [3]. In general, damage to buildings is the main reason for loss of life as well as financial losses from earthquakes. The collapse of buildings results in casualties, either through crushing or entrapment.

Base isolation is one of the most powerful and popular tools for earthquake protection of structures [4]. During the action of an earthquake, these structural elements essentially decouple the superstructure from the substructure and thereby restrict the transfer of seismic forces into the superstructure [5]. Hence, the resulting bending moments and shear forces in the superstructure will be much less than that of a building without base isolation. That means, rather than increasing the capacity, the demand of the system is reduced by installing a base isolation device. In short, base isolation makes a structure flexible by lengthening the natural period and enhancing the damping and thereby reduces the transmissibility of ground motion to the superstructure [6].

2 Types of Base Isolation Systems

2.1 Conventional Isolators

Base isolator is a seismic protection system which reduces the ductility demand of a building by increasing the natural period of structure vibration out of the high-energy range of an earthquake. The conventional isolators include elastomeric bearings and friction bearings. Elastomeric bearings are the most commonly used type of bearings, and they make use of the hyper-elastic and damping properties of rubber in enhancing the flexibility of structures. It mainly consists of rubber layers sandwiched between steel plates and acts as a single unit. Steel plates provide vertical stiffness and prevent lateral bulging during an earthquake. The

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elastomeric bearings (Fig. 1 (a)) are further classified into natural rubber bearings, synthetic rubber bearings and lead rubber bearings. The lead rubber bearing is provided with an additional lead plug at the centre to enhance the energy dissipation characteristics. Friction pendulum bearings (Fig. 1 (b)) consist of a globe-like structure placed between two concave curved surfaces. These bearings dissipate energy by the friction between its components during the action of an earthquake. Figure 2 shows seismic isolation of a building (Bhuj hospital) using Lead rubber bearing.

Figure 1: *Seismic isolation devices-* **(a)** *elastomeric bearing,* **(b)** *friction pendulum bearing.*

Figure 2: *Lead rubber bearings provided at Bhuj hospital, India.*

The huge production cost, due to labour-intensive manufacturing and vulcanization processes, makes the application of conventional isolators limited to large, expensive, and sophisticated structures [7]. Even though an earthquake is a frequent phenomenon in many parts of the world, this technology has not been adopted in most of the cases even if it is required as it is costly. But the availability of a simple and affordable seismic isolation system may enhance the use of seismic isolators as a protection system. Scrap tyre pad isolators provide an economically feasible alternative of the expensive conventional seismic base isolation systems.

2.2 Scrap Tyre Pad Isolator

The scrap tyres have been in use as a secondary material in civil engineering applications because of their excellent mechanical properties [8]. The idea of using a scrap tyre pad as a material for base isolation has evolved from the fact that it contains both rubbers as well as intervening steel strands. It is expected that rubber will contribute to lateral flexibility and steel will contribute to vertical stiffness if used as an isolator [9]. The tread portion of the tyre can be cut into pads of definite size (Fig. 3 (a)) and arranged one above the other to form the isolator (Fig. 3 (b)). A scrap tyre pad isolator is advantageous over conventional seismic isolation systems as there is no additional cost for its manufacturing, ease of handling, weight reduction, and simple shear stiffness adjustment by varying the number of layers [10]. Also, the environmental issues due to the recycling of tyres can be reduced by reusing this material which is non-biodegradable.

Figure 3: (a) *Scrap tyre pad,* **(b)** *Scrap tyre pad isolator. (Source: Turer et al,* [10]*)*

3 Structural Properties of Base Isolators

The structural properties of isolators include compression and shear properties. The compression properties such as vertical load-carrying capacity and vertical stiffness can be estimated from the compression test of the isolator. The shear properties of isolators are studied with the help of reverse cyclic load tests at constant vertical pressure. The load-displacement response is used to estimate the effective lateral stiffness and damping properties. Figure 4 shows the shear response of a base isolator. The shear properties of the isolator can be estimated from the hysteresis loop. In figure 4, the initial slope Ke indicates the elastic stiffness of the isolator before yielding and Kd is the yielded stiffness. Kd is a function of the area and height of the isolator. The effective stiffness Keff is a function of displacement. Yield force Fy indicates the force at which behaviour changes from linear to non-linear. The above parameters can be estimated from the hysteresis loop of the isolator.

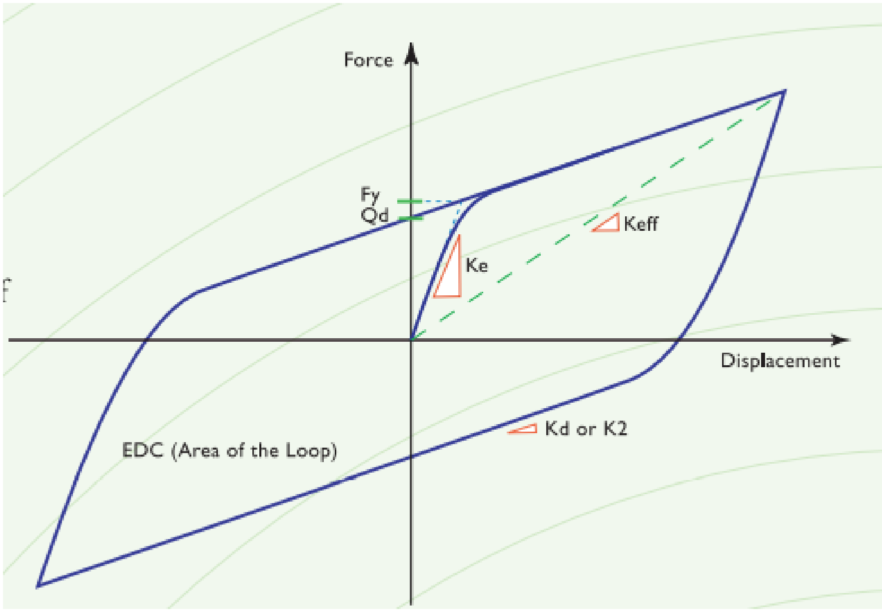

Figure 4: *Force-displacement loop of conventional isolator*

(Source: http://www.dis-inc.com/technical.html)

The structural properties of the isolator are mainly governed by its plan area and aspect ratio. The larger the plan area, the larger will be the vertical load-carrying capacity. But there is a limitation in increasing the area of the scarp tyre pad isolator as the tread width of commonly used tyres is in the range of 150-300 mm. Studies reveal that the tyre composite is capable of withstanding high vertical pressure. Also, increasing the total number of isolators in a structure may limit the vertical pressure acting on each of them. The scrap

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tyre pad isolators exhibit excellent horizontal stiffness characteristics and are capable of undergoing large rollover deformation and thereby making the structure flexible [11].

4 Methodology

The study reported in this paper includes the performance analysis of a framed structure, with and without scrap tyre pad base isolators, using ETABS 2020. The performance is also compared with that of conventional Lead Rubber Bearings (LRB).

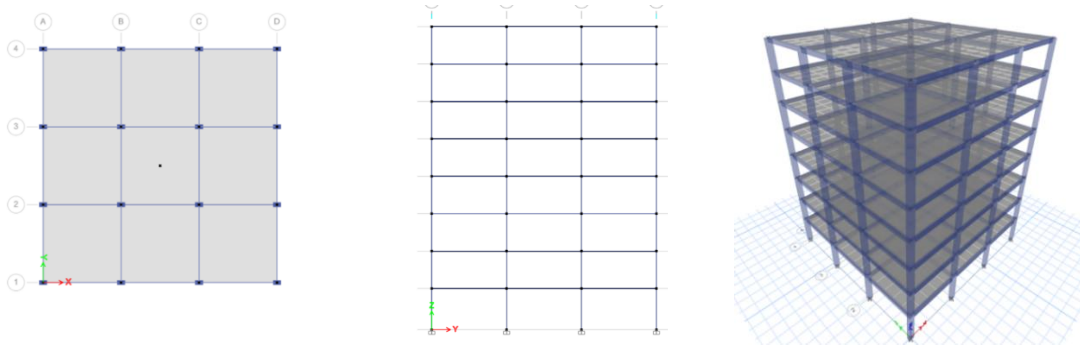
4.1 Building Model Parameters

For the present study, a symmetric G+7 storied structure is selected. The building is assumed to be situated in seismic zone III and the soil condition is assumed to be of rock type. The details of the building are given in table 1.

Table 1: *Building model parameters.*

I	**Building Description**	
	Number of storeys	G+7
	Plan area	18 m ×18 m
	Storey height- bottom storey -other storeys	3.3 m 3.0 m
	Total height of building	24.3 m
	Thickness- outer wall	230 mm
	Thickness- inner wall	115 mm
	Seismic Zone	III
	Structure frame system	SMRF
	Importance factor	1
II	**Material Properties**	
	Grade of concrete	M40
	Grade of steel	Fe 415
	Density of concrete	25 kN/m^3
III	**Loads Considered**	
	Live load	3 kN/m^2
	Floor finish	1 kN/m^2

A three-dimensional Finite element model of the framed structure is simulated in ETABS 2020 (Fig. 5). The fixed base condition is simulated by providing fixity at the base. Floors are modelled by assigning rigid diaphragm constraints at each level. The beam, column and slab sizes are fixed based on the applied loads as per RCC design requirements. A bilinear model is used to simulate the properties of the isolator and is adopted from the horizontal force-displacement hysteretic response of the isolators. The property is assigned using the link property element in ETABS.



(a) *(b)* *(c)*

Figure 5: *Building model in ETABS –* **(a)** *elevation,* **(b)** *plan and* **(c)** *3D view.*

4.2 Design of Isolator

Initially, the natural time period of the structure is found to be 1.42 s from the modal analysis. In order to make the structure flexible, the target isolator stiffness is identified based on the target time period. Also, the optimum number of isolators is decided based on the vertical load-carrying capacity of isolators.

Conventional lead rubber bearings are produced in large quantities and widely used across the world. A suitable type of lead rubber bearing was adopted from commercially available seismic isolators based on the design requirements for the selected building model. The isolators are provided between the plinth beam and the substructure. Based on the vertical load carrying capacity and total vertical load from the superstructure the number of isolators is fixed as 16. On the periphery and corners, the vertical pressure is slightly high, hence the isolator with a slightly higher diameter is adopted. The properties of the adopted LRB isolators are given in table 2.

Table 2: *Properties of Lead Rubber Bearing*

Sl No	Isolator properties	LRB outer	LRB inner
i	Yielded horizontal stiffness	420.625 N/mm	400.427 N/mm
ii	Effective horizontal stiffness	653.107 N/mm	633.107 N/mm
iii	Yield Force	220 kN	180 kN
iv	Diameter	650 mm	520 mm
v	Isolator height	380 mm	380 mm
vi	Number of layers	24	24

From the findings so far, the main limitation of scrap tyre pad isolators is the inability to sustain heavy vertical loads. Hence assigning isolators directly below the columns may not be effective in this case. In order to reduce the vertical stress on each isolator, additional beams are assigned at the plinth level and isolator positions are fixed accordingly. In this way, 28 isolator positions are identified for the selected frame in order to distribute the vertical pressure. The isolator layout for both LRB system and STRP system is given in figure 6 (a) and 6 (b).

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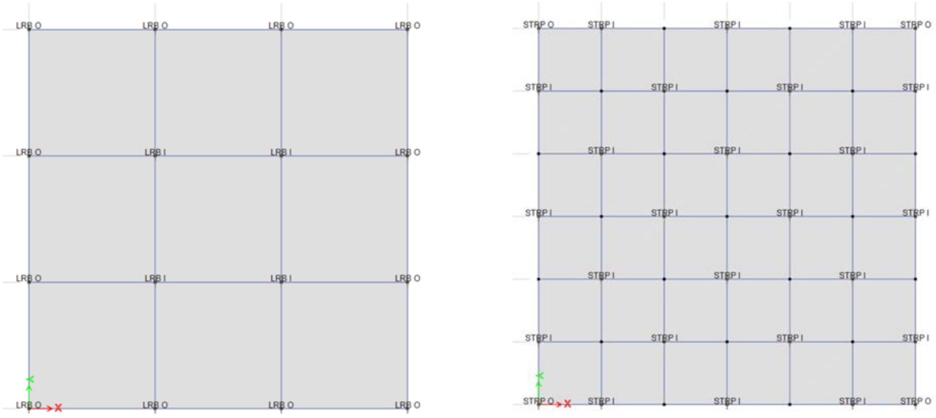


(a) (b)

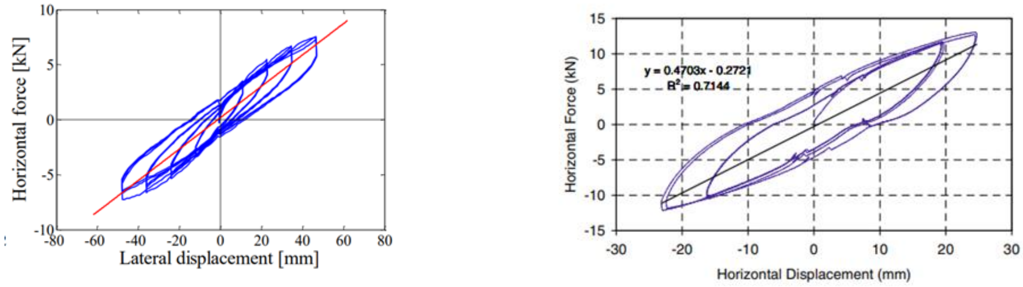
Figure 6: *Plan of building model with* **(a)** *LRB and* **(b)** *STRP*

The required horizontal stiffness is identified as per the design requirements. But only limited data is available for adopting this type of isolator for commercial use. As per the design, the total horizontal stiffness required for the structure is estimated to be 10129.73 N/mm along both X and Y directions. Since there are 28 isolators, the average stiffness required for the isolator is 361.776 N/mm. As scrap tyre pad isolators with the above property is not available, it is required to use available isolators so that the total horizontal stiffness provided by the isolators matches with the design stiffness. The scrap tyre pad isolator reported by Mishra et al. [9] (1) has a horizontal stiffness of 142.5 N/mm. Turer et al. [10] (6) has reported an isolator which gives horizontal stiffness of 548 N/mm and 579 N/mm along two orthogonal horizontal directions. In the present study, isolator reported by Mishra et al. [9] is provided at the corner positions and isolator suggested by Turer et al. [10] is used at other locations. The details of isolator properties are provided in table 3. Also, the force-displacement hysteretic response of the isolators is given in figure 7 (a) and 7 (b).

Table 3: *Properties of scrap tyre pad isolator*

Sl No	Isolator properties-STRP	STRP at corners	STRP at locations other than corners
i	Dimensions	100×100×72 mm	200×180×46 mm
ii	Effective horizontal stiffness (Longitudinal)	142.5 N/mm	548 N/mm
iii	Effective horizontal stiffness (Transverse)	142.5 N/mm	579 N/mm
iv	Number of layers	6	4

Using the selected isolators, the total stiffness comes out to be 13722 N/mm and 14466 N/mm in X and Y directions respectively. It may be noted that there is a variation of about 25% in the adopted stiffness compared to the design stiffness.



(a) (b)

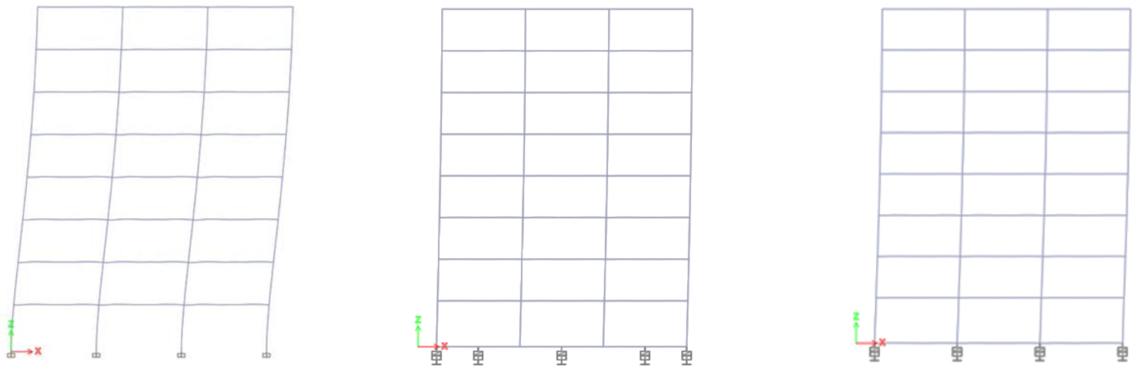
Figure 7: *Load displacement hysteresis of STRP adopted for-* **(a)** *Outer Isolators* [9] *(Mishra et al.),* **(b)** *Inner Isolators (Turer et al.)* [10]

The building performance is analyzed with and without isolators using Response Spectrum analysis in ETABS 2020 as per IS 1893:2016. The storey response is evaluated for each model and the variations in storey displacements, drift and acceleration are compared. The variations in time period of the structure and base shear are studied.

5 Results And Discussion

5.1 Lateral Displacement and Storey Drift

The fixed base model undergoes large lateral deformations under the action of earthquake load. But in the case of base-isolated models, the lateral deformation is comparatively high at the base level due to the action of the isolator. But the lateral displacement of floors with respect to the base is found to be less. In other words, the storey drift is reduced considerably with the addition of isolators both in the case of LRB and STRP in both X and Y directions. Figure 8 shows the deformed shape of fixed base, STRP isolated model and LRB isolated model.



(a) (b) (c)

Figure 8: *Deformed shape of models in response spectrum analysis-* **(a)** *fixed base model,* **(b)** *model with STRP and* **(c)** *model with LRB*

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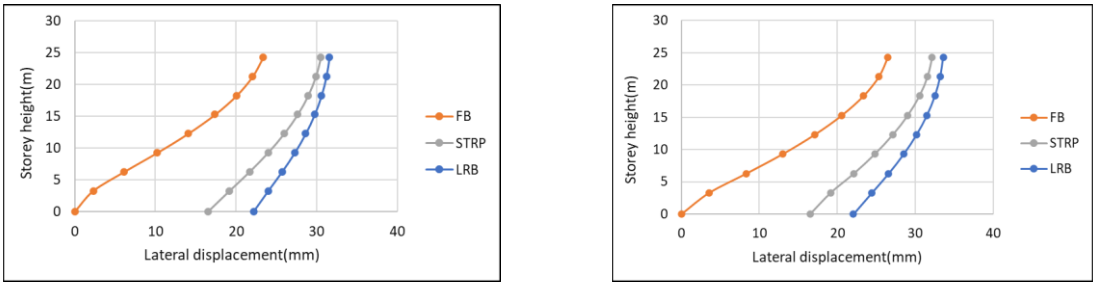
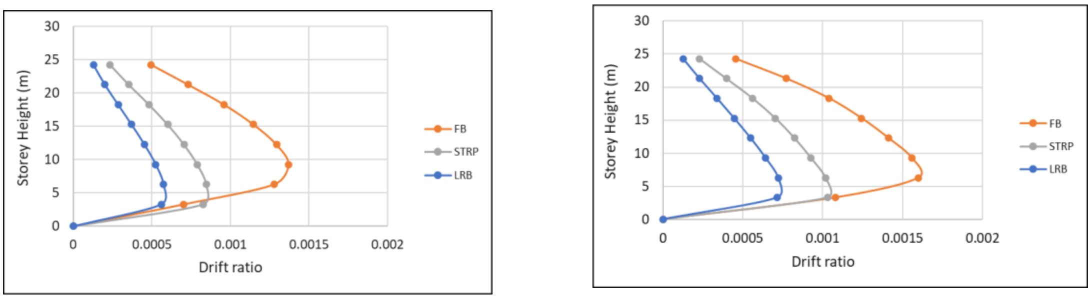


(a) (b)

Figure 9: *Lateral displacement of various models –* **(a)** *along X direction* **(b)** *along Y direction*

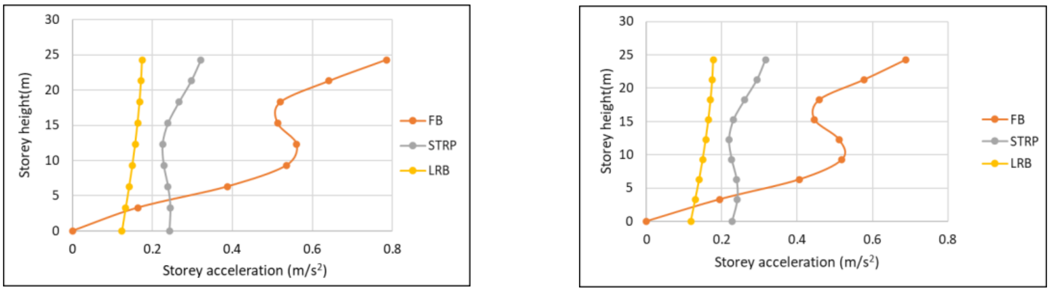


(a) (b)

Figure 10: *Drift ratio of various models–* **(a)** *along X direction* **(b)** *along Y direction*

For the fixed base model, a maximum storey drift ratio of 0.001371 is observed at a height of 9.3 m from the base in X direction. The drift ratios reduced to 0.00079 and 0.000525 with STRP and LRB respectively. The reduction in drift is about 42% in the case of STRP isolated model and 63% in the case of lead rubber bearing. In Y direction, maximum drift is observed at a height of 6.3 m. The maximum drift ratio reduced to 0.001018 and 0.000722 respectively with STRP and LRB. The reduction is about 36% for STRP and 54% for LRB.

5.2 Storey Acceleration



(a) *(b)*

Figure 11: *Storey acceleration of various models –* **(a)** *along X direction* **(b)** *along Y direction*

It is observed that with the addition of isolators, storey acceleration reduced considerably in both X and Y directions. On comparing the performance of isolators, the reduction in acceleration with LRB is much higher than that with STRP. For all cases, maximum storey acceleration is observed at the roof level. The storey acceleration reduced to 33.33% by assigning STRP and to 20% by assigning STRP and LRB in X direction. Similarly, Storey acceleration reduced to 50% and 25% with the addition of STRP and LRB in the Y direction.

5.3 Base Shear

In a conventional fixed base structure, the earthquake forces are transmitted to the structure and hence the resultant base shear will be high. But in the base-isolated building model, the isolator restricts the transfer of earthquake forces into the superstructure. As a result, there is a significant reduction in base shear. The base shear is found to be reduced by 42.56% in the case of the model with STRP and by 59.41% in the case of the model with LRB.

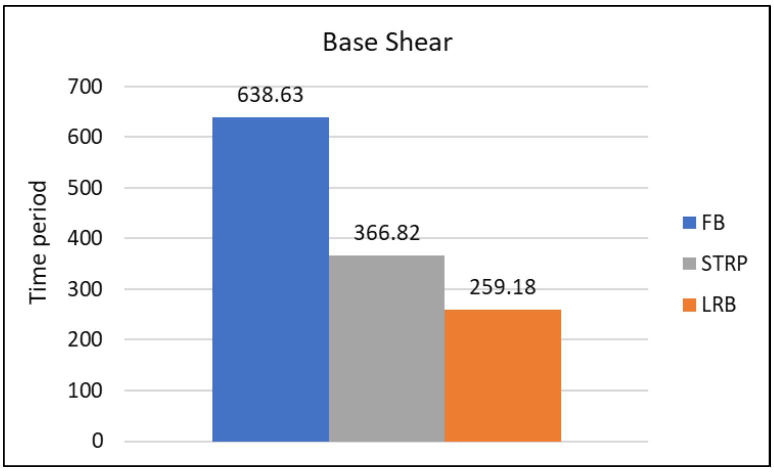


Figure 12: *Reduction in base shear with STRP and LRB isolators*

5.4 Time Period

By assigning an isolator the structure becomes flexible and hence the resultant time period will be high. For the present study, the time period increased by nearly 2 times for both STRP isolated model and LRB model.

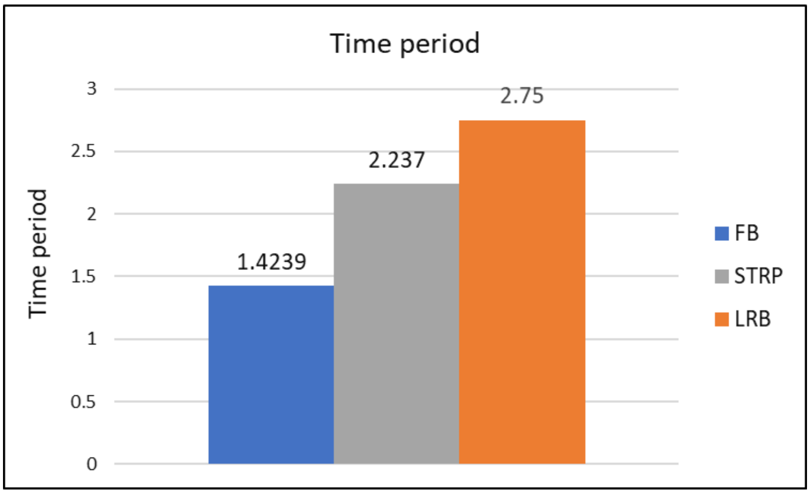


Figure 13: *Enhancement of time period with base isolators*

The overall performance of STRP isolators adopted in the present study is found to be slightly inferior to that of the LRB isolators. It may be noted here that the STRP isolators for the present study is adopted from the reported literature such that the isolator parameters match with the design parameters. Due to the unavailability of STRP isolators with matching parameters, isolators with parameters which are close to the design parameters are adopted. Better performance of STRP isolators in seismic isolation can be expected if the isolator parameters exactly match with the design parameters.

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6 Conclusions

In the present study, an attempt has been made to compare the performance of scrap tyre pad isolator with a conventional isolator in the seismic response control of a G+7 frame. The conventional isolator considered in the study is the Lead Rubber Bearing isolator. Response spectrum analysis is carried out on fixed base frame, model with STRP and model with LRB.

On comparing the performance of fixed base and base isolated building models, the performance of both STRP isolated and LRB isolated models is found to be improving significantly with the addition of isolators. It is observed that the base-isolated models undergo large lateral deformations at the base level along with a significant reduction in drift at higher levels. The reduction in drift is about 42% for the model with STRP and 63% for the model with LRB in X direction. Similarly, the reduction is 36% and 54% respectively in Y direction. With the addition of isolators, storey accelerations reduced considerably in the case of both STRP and LRB in both X and Y directions. For the fixed base model, maximum storey acceleration is observed at roof level which was reduced to 33.33% and 20% with the addition of STRP and LRB respectively in X direction. Similarly, accelerations are found to be reduced to 50% and 25% respectively with the addition of STRP and LRB in Y direction. The addition of isolators enhances the performance of the building by increasing the time period and reduce demand by reducing base shear. The increase in the time period is almost 2 times for both cases as designed and the reduction in base shear is about 42.56% and 59.41% for STRP and LRB respectively. For the limited study carried out, the performance of STRP base-isolated building model is found to be inferior to that of LRB base-isolated building in terms of lateral displacement, drift, storey acceleration time period and base shear. This is mainly because of the slight mismatch in properties of the adopted isolator with the parameters actually required as per the design. Also, the lateral deformation capacity of scrap tyre pad isolator is less when compared to conventional huge isolators.

It is worth mentioning here that the properties of STRP are adopted from the limited data available from the published literature. The performance of STRP isolators can be further improved by adopting isolators with parameter values that exactly match the design requirements. Detailed research on different variations of scrap tyre pad isolators is expected to provide sufficient data on the properties of scrap tyre pad isolators which in turn help the designers to devise seismic base isolators for structures with a wide range of fundamental time periods. Also, increasing the area of scrap tyre pad isolators may enhance the vertical load-carrying capacity and lateral deformation capabilities and thereby improve their performance in multistoried buildings.

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