Malaysian Journal of Civil Engineering 26(1):51-61(2014)

RECYCLE TIRE ISOLATOR AS EARTHQUAKE RESISTANCE SYSTEM FOR LOW RISE BUILDINGS

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Abstract: The purpose of this research is to study the use of Recycle Tire Isolator (RTI) as earthquake resistance system to protect low rise buildings from life threatening collapses and casualties when earthquake takes place. Many buildings are built with seismic design based on the concept of increasing the resistance capacity of the structures by using shear walls, braced frames and others. However, these methods result in high floor accelerations and could cause significant damage to nonstructural components of the buildings. Some of these buildings' content are quite costly. Hospitals and government offices, for example, are important premises which contain valuable machines or documents such as X-rays machines and the data stored in computers. RTI could be installed at the pad foundation to absorb low to moderate earthquake energy which is less than 6 Richter scale. The isolator uses recycle tire as main component to absorb lateral forces produced during earthquake. The use of RTI also helps to reduce the hazard of dumping old tires on earth. This study focuses on the role of RTI in protecting two stories buildings. The displacement of RTI was measured when vertical or lateral forces were applied. Compression test using Universal Testing Machine was carried out in the laboratory to find the maximum vertical load. The vertical load was applied to the specimen by the vertical hydraulic actuator in displacement control. The specimen was monotonically loaded to failure. COMSOL Multiphysic V4.2, a finite element software was used to model the behavior of RTI and the results were compared to the results obtained from laboratory. The behavior of RTI was also compared to the behavior of existing rubber bearing (RB) and scrap tire pads (STP). The results of laboratory and finite element analysis indicated that RTI could support a maximum axial load of 184 kN and lateral force up to 20 kN. Based on the results, RTI had a potential to be used as a device to protect low rise buildings against low to medium earthquake. The compressive strength of RTI and STP was quite similar with about 6.7% difference. This was expected since both materials were recycle tires. The compression modulus between RB and RTI was also similar with about 11.1% difference. This showed that RTI had similar features with RB and STP. However, RTI fabricated mainly by using recycle tires contained about 4 to 6 layers of steel mesh which was stiffer than RB and more efficient in supporting heavier structures vertically. The use of recycle tires in production of RTI made it more affordable for most house owners compared to RB or STP.

Keywords: *Recycle tire, earthquake, low rise buildings, old tires, comsol multiphysic v4.2*

1.0 Introduction

When earthquake occurs, the base of the building will move in harmony with the ground, but the upper part of the building will experience inertial forces. These inertial forces can be explained by using the analogy of a passenger in a moving vehicle. The passenger may experience inertial forces whenever the vehicle is accelerating or decelerating. If the vehicle is accelerating, the passenger will be pushed backward against the seat but when the vehicle is decelerating or breaking, the passenger will be thrown forward in the seat (WHO, 1994).As the effect of earthquake, structures are mainly affected by the horizontal forces. The vertical forces are usually less than 50% of the horizontal ones. The immediate effects on the buildings are the building’s wall might fall, structure might crack and eventually the roofs collapse. The methods of construction for buildings less than four stories in height are typical and design engineers do not consider earthquake forces. However, past histories reveals that when earthquake happens, the low rise buildings are prone to severe damages in comparison with high rise buildings. One of good example is the earthquake occurred at Haiti on 12 January 2010. It was estimated 250,000 residential which consist mainly low rise buildings collapsed (U.S. Geological Survey, 2010). Isolation is an effective way of protecting buildings from earthquake. An extensively used isolator which is Steel-reinforced elastomeric isolator is expensive and heavy (Beom, 2008). Therefore, Recycle Tire Isolators (RTI) were proposed to be installed in the structural base to reduce the vertical and horizontal displacement of building caused by earthquakes in a lower cost and weight.

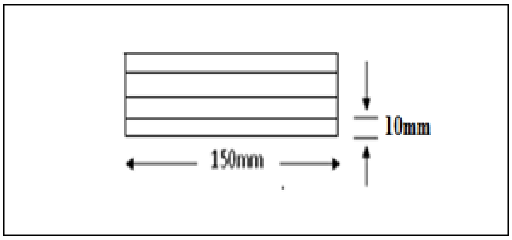
2.0 Materials and Methods

2.1 Materials

Steel Plate was one of RTI component. It was used to give better support to vertical load. The normal yield strength grades for steel available were 195, 235, 275, 355, 420, and 460 (British Standard Institute, 2001). Bolt and nut are used to connect the steel plate of RTI to the pad foundation to give a firm connection between the RTI and the pad foundation. Used tires were the main elements in manufacturing RTI. The elasticity features of the tire made it suitable in absorbing lateral forces.

2.2 Preparation of RTI

The old tire was first cut into small pieces measuring 150mm x 150mm x 10mm thick tire pad. The tire pads were then arranged in four layers as shown in Figure 1(a) and 1(b).The cut tire pads were sticked together by using two tons high strength grout. The grout was applied on the dry tire pad surface. After the tire pads were sticked together using the high strength grout, pressure was applied on the tire pads to ensure they sticked well. Concrete beams were put on top of the tire pads for at least 24 hours so that the grout was completely dry as shown in Figure 1(c).



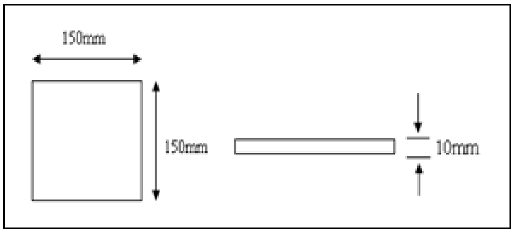


Figure 1(a) Figure 1(b)

Figure 1(c)
Figure 1: Arrangement of tyre pads

2.3 *Loading Calculation*

Figure 2 shows the sketch of a double stories building. The method of calculating the loading which was based on BS8110 (British Standard Institute, 1997).

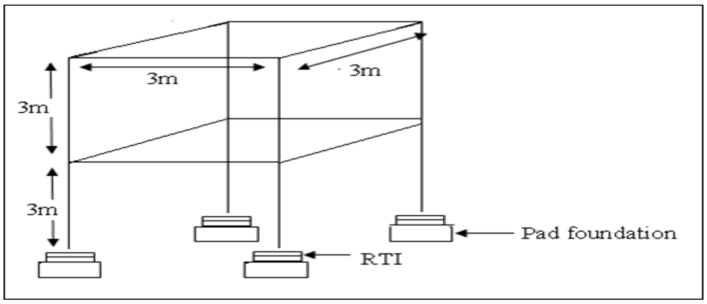


Figure 2: Sketch of Double Stories Building

Table 1 shows the loading per column for double stories buildings. The types of buildings listed in the table were considered as important premises. The size of the building was assumed as 3 m wide x 3 m long x 6 m high. The distance between column to column was normally 3m according to the common design practices in engineering. The live load taken was based on the guidelines in BS 6399:part 1 : 1984 (British Standard Institute, 1984). The loading was dependent on the type of floor area usage. For example, if the floor area usage was the bedrooms of a residential, the intensity of the distributed load adopted was1.5 kN/m^2. The dead load of the buildings included the brick walls and the self weight of the concrete structures.

Table 1: Loading for Double Stories Buildings

Type of Building	**Intensity of distributed load (kN/m^2)**	**Load per column (kN)**
Residential House	1.5	69.8
Bank	3.0	76.5
Hospital	3.0	76.6
School	5.0	85.5

3.0 Results and Discussion

3.1 Compression Test

Four Samples of RTI made up of four layers used tire pads were tested under axial load with gradual increments using Universal Testing machine as shown in Figure 3. The dimension of each test sample of RTI was 150 mm x 150 mm x 10 mm tire pads with 4 layers of thickness. The dimension of RTI and Rubber Bearing (RB) were the same except that RB has only one layer. However, RTI and RB were same in height which was 40 mm. The STP was in rectangular shape. It had a slightly bigger in terms of area and 6 mm thicker than RTI and RB.

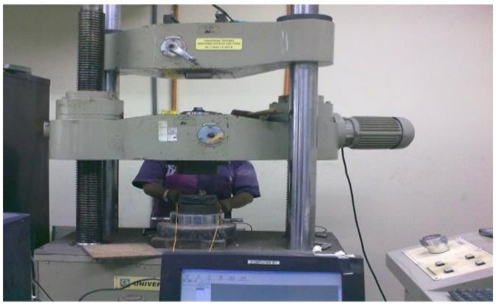


Figure 3(a)
Figure 3(a) : UniversalTesting Machine

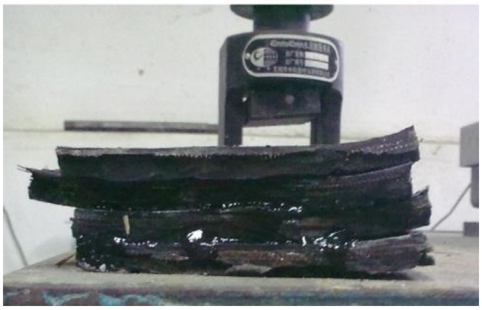


Figure 3(b)
Figure 3(b) : Sample at failure stage

From Table 2, the strength of Rubber Bearing (RB) was the highest whereas the strength of RTI and STP were almost similar. The main reason was that the material used in RTI and STP were similar which was recycle tire. RB was using elastomeric pad containing a single layer of 3 mm thick steel plate. The difference in strength between RTI and STP was about 7.4%. Beside the slight different in dimension, the higher strength of STP could be due to the different type of tire brand used as well. In this study, the tire brand used was Bridgestone.The compression modulus were compared among the specimens at strain of 0.1 MPa. The compression modulus between RB and RTI were almost similar with the difference of about 12.5% even though they contained different material. However, STP had a slightly higher compression modulus. The thickness could be one of the factor because thicker sample will sustain higher stress. The two samples of RTI presents quite close results for compressive strength and Compression Modulus which were expected. Instantaneous compression modulus E values of all specimens were calculated using the formula in Eq: 1

$$E = \frac{d\sigma}{d\varepsilon} \tag{1}$$

where E is Compression Modulus, σ is stress and ε is strain.

Table 2: Compression test results of Rubber Bearing (RB), RTI and Scrap Tire Pad (STP)

Type	Dimensions (mm)	Number of Layers	Strength (MPa)	Compression Modulus at ε=0.1 (MPa)
RB	150x150x40	1	42.2	25
RTI (Sample 1)	150x150x40	4	8.2	20
RTI (Sample 2)	150x150x40	4	8.1	25
RTI (Sample 3)	150x150x40	4	8.2	28
RTI (Sample 4)	150x150x40	4	8.2	26
STP	200x180x46	4	8.7	33

Based on Figure 4 to 11, the compression modulus and axial load capacity of the four Samples of RTI remained almost similar with close pattern of stress-strain responses because all of them were manufactured from same materials. The vertical displacement of RTI at maximum axial force was about 9 mm. The maximum axial force applied was about 184 kN for both samples. The samples start to fail at this force. The samples showed non linear behavior when the strain was below 0.1. The results were more linear when strain was between 0.1 and 0.2. This is due to the bonding of the RTI pads when the glue was applied in between the pads. It was found that there were some small gaps in between each layer of RTI pads after they were stacked together. When the vertical load was started applied to the RTI, the gaps in between each layer were reduced and the layers was then fully attached to each other after a short while. This phenomena will contribute to the occurrence of the non linear part of the graph. Then the sample started to behave linearly when the load was continually applied. The maximum stress was about 8 MPa which happened at strain of about 0.23%. Figure 12 show that at the same strain levels, the instantaneous compression modulus values of RTI specimens were higher than that of the RB values. The slope changes of RTI specimens started earlier and failed at much lower strains compared to RB specimen. The RB specimen had only a single steel layer which perform smaller vertical stiffness and larger vertical strain in comparison to RTI. RTI samples cut from used tire were harder due to the present of 4 to 6 layers of wire mesh. The high vertical stiffness of RTI layers combined with relatively low amount of steel content made RTI layers stiffer but lower strength compared to RB.

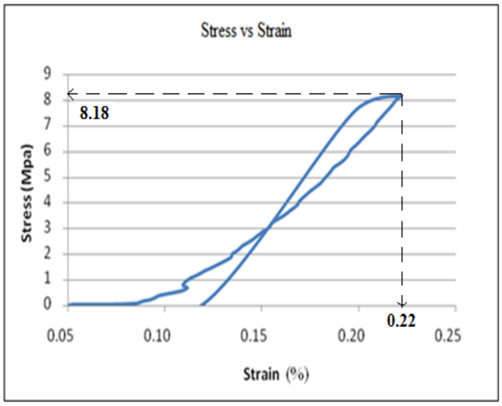


Figure 4: Stress vs Strain for Sample 1 - Bridgestone

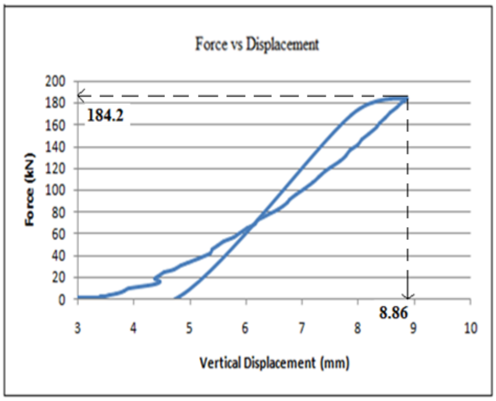


Figure 5: Axial Force vs Vertical Displacement for Sample 1- Bridgestone

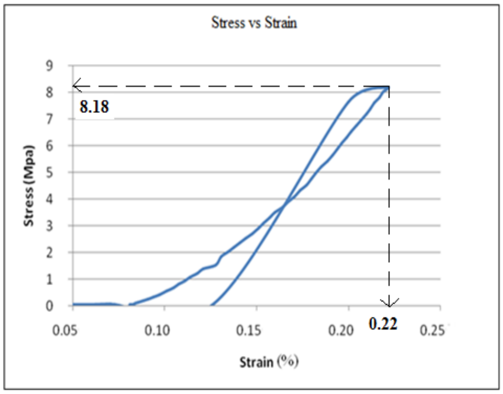


Figure 6: Stress vs Strain for Sample 2 - Bridgestone

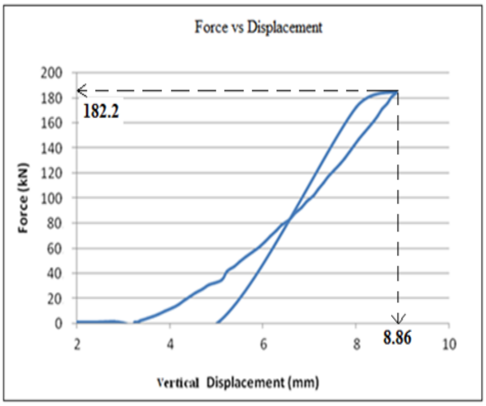


Figure 7: Axial Force vs Vertical Displacement for Sample 2- Bridgestone

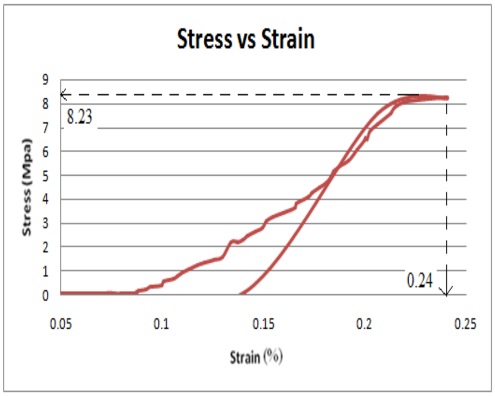


Figure 8: Stress versus Strain for Sample 2 - Dunlop

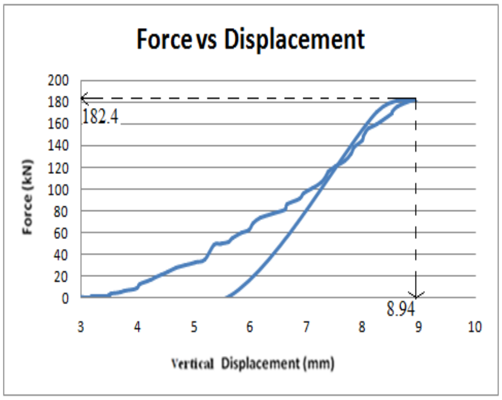


Figure 9: Axial Force versus Vertical Displacement for sample 2-dunlop

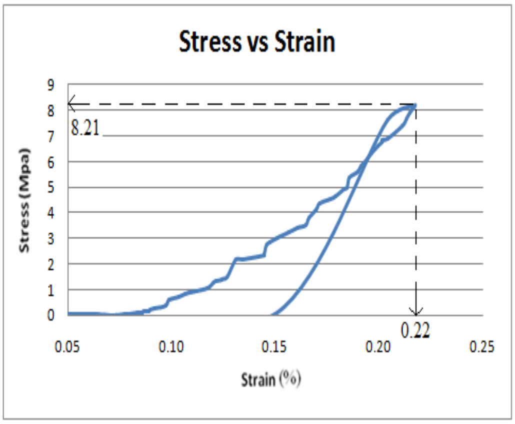


Figure 10: Stress versus Strain for Sample 4 - Falken

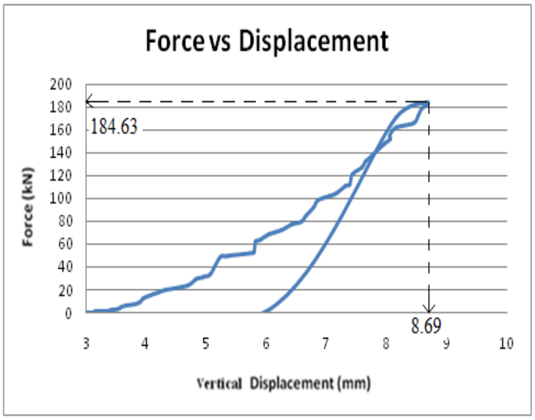


Figure 11: Axial Force versus Vertical Displacement for Sample 4-Falken

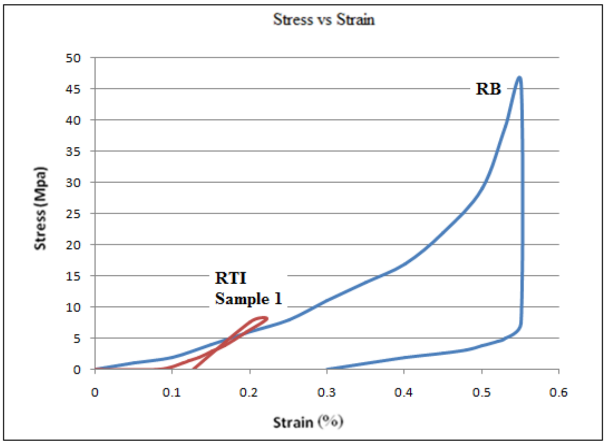


Figure 12: Compression Test and Comparison of RTI (sample 1) and RB sample (Turer and Ozden, 2008)

3.2 *Finite Element Analysis*

Table 3 shows a series of finite element analysis carried out to compare the behavior of RTI under different lateral forces. Four models with similar dimension were analyzed. The rubber material of RTI was modeled using square elements. The top and bottom of the RTI were defined as fixed constrain to represent the superstructure and substructure respectively. In this model, the vertical load were applied on the top support and the horizontal loads were applied at the side. When the horizontal loads applied was between 0 to 10,000 N, the horizontal displacement was not significant until when the load was increased from 10,000 N to 20,000 N, the horizontal displacement showed value between 10 mm to 15. All the four models showed the same vertical displacement as the compressive load was constant.

Table 3: Horizontal and Vertical Displacement at Different Lateral Forces

Case no	Lateral Forces (N)	Vertical Forces (kN)	Horizontal Displacement (mm)	Vertical Displacement (mm)
1	0	184	0	8
2	50	184	0	8
3	10000	184	10	8
4	20000	184	15	8

4.0 Conclusions

This research has managed to achieve all of its objectives. The first objective is verified by results of various lateral forces on the horizontal displacement of Recycle Tire Isolator (RTI) with a fixed vertical load. The model shows deviation of about 15 mm and quite out of shape when the lateral loads increased to 20 kN which is about 10% of the maximum vertical loads. The second objective is achieved when RTI is loaded at maximum load of 184 kN, it deforms vertically by 8.86 mm in laboratory experiment and by about 8 mm in finite element analysis. Therefore, the laboratory experiment and the finite element analysis have a close agreement. For the third objective, it is also achieved since RTI shows some similarities with Rubber Bearing (RB). RB has been implemented in some of the buildings as an isolator. However, the cost of manufacturing is not cheap. since RTI has similar properties and functions as RB, it could be an alternative to install it in the foundation of low rise buildings. The outcomes of this research are important to the engineering field due to the effects of earthquake are getting significant even in countries which are out of earthquake zone such as Malaysia. Most of low rise buildings are not protected with earthquake resistance systems. Therefore, RTI is introduced as an economical system to resist medium earthquake force. RTI not only simple in term of installation but also affordable for most of the house's owner. When medium earthquake happens, the use of RTI in the building foundation will reduce the possibilities of collapse thus safeguard the valuable items in the building and protect the life of the occupants. Some equipments and documents are very expensive and important in building such as hospital. It will be a big lost if these equipments and documents are destroyed. The results of finite element analysis and laboratory experiment of RTI indicates that RTI can be used as a base isolation device for earthquake protection for low rise residential or commercial buildings. The main material used in RTI is recycle tire. It not only helps to reduce the amount of used tires in dumping area but the used tire also has the similar characteristic as other commercial available rubber damper. From the study, RTI can support a maximum axial load of 184 kN which exceeds the loading per column of double stories buildings.

5.0 Acknowledgements

The authors would like to thank Ministry of Higher Education for funding this research through Grant ERGS/1/2011/TK/UKM/02/19 and Universiti Kebangsaan Malaysia through Grant GUP-2012-029.

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