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RECYCLED TIRE ISOLATOR AS EARTHQUAKE RESISTANCE SYSTEM FOR SINGLE STOREY BUILDING IN MALAYSIA

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Abstract

The studies of seismic isolation have gradually become important particularly in countries of active seismicity activity. The main idea of isolation is to provide flexibility to the structural foundation as well as to absorb energy and mitigating ground acceleration generated from earthquake forces. However, the cost to manufacture conventional commercial rubber isolator is high due to its heavy weight complicated in the process of preparation involving expensive machinery. When earthquake occurs, the building structure especially low rise residential buildings such as single storey buildings are subjected to high inertia forces which lead to structural damages. Country such as Malaysia which located outside the earthquake region is now even facing the threat of earthquake too in some areas especially Sabah. This alerts Malaysia that there is a need to develop an earthquake resistance mechanism. Recycled Tire Isolator (RTI) is a model designed to be embedded into the foundation of a low rise building in order to withstand earthquake forces. The main component in the fabrication of RTI is recycled tire. The useable section of the recycle tire is the tread and will be split into small pieces with measurement of 300mm x 210mm. Each piece of cut tire is about 10mm thick. The method of preparation of RTI samples is simple which is cost effective and sustainable. RTI samples consist of four to five layers of cut recycled tire pads. Static compression test was conducted to examine the vertical capacity of RTI. A controlled vertical force of 380 kN (maximum capacity of the compression test machine) was applied on to the RTI during the compression test. An average displacement of 11.5mm was recorded when the cracking sound was heard indicating the failure of RTI sample. The static or vertical stiffness of RTI was determined. Besides, dynamic compressive load test was another experiment carried out to examine the damping coefficient, damping ratio and also dynamic stiffness of RTI. The results obtained from the experiment were compared with the commercial available isolators and also compared among the RTIs. The similarities of characteristics between RTI and the commercial isolators have given an indication that RTI has great potential to be adopted as earthquake base isolator for single storey residential buildings.

Keywords: Earthquake, isolation, recycled, sustainable, single storey,

1.0 INTRODUCTION

Malaysia is a country located outside the earthquake active region. However, earthquakes are expected in Sabah, which is considered as having a high level of seismicity than Sarawak and Peninsula Malaysia (Lam, N.T.K., 2016). The AM5.9 earthquake on the Richter Scale that occurred in Ranau, Sabah, give an indication that Malaysia needs to take precautions to protect the buildings structures especially single storey residential houses. RTI is proven to be suitable to be used as isolator to prevent single storey building from collapse during earthquakes. Isolation from the ground during a seismic excitation has been one of the challenging issues for researchers. The general principle is to disconnect the building from the lateral force of the earthquake by interposing a layer with elastic element between the foundation and the superstructure. (Hossein Monfared and Ayoub Shirvani and Sunny Nwaubani, 2013). A Few studies have been conducted on steel laminated rubber bearing and fiber-reinforced elastomeric isolators to be used as earthquake resistance system at seismic regions of the world. However, these types of seismic isolator still unaffordable by poor families in the South Asian region. As a solution, an economical and sustainable base isolation using recycled tire pads is introduced and to be installed at the foundation of low rise residential houses particularly for single storey buildings (Huma Kanta Mishra and Akira Igarashi and Hiroshi Matsushima, 2012). Furthermore, the main material in the component of RTI comes from scrap tire. Massive disposal sites of scrap tires are common in many cities and statistic shows that one scrap tire is produced per person every year (Ahmet Turer, 2012). Manufacturing of RTI can reduce the disposal problem of scrap tires.

2.0 LITERATURE REVIEW

The fault zones in peninsular Malaysia are not very active compared to Indonesia and Philippines. The faults lines scattered across the peninsular are Temengor fault line, Kenyir fault line, Manjung fault line, Bukit Tinggi fault line and Kuala Pilah fault line. Although these fault lines are not active currently, however, there is no assurance that they will become active one day in future. Meteorology Department of Malaysia have recorded numerous earthquake events in Sabah since 1966 as shown in Figure 1.

The earthquake magnitude ranging from 5.3 to 6.2 in Richter Scale. Most the earthquake events occurred around Kota Kinabalu which the shortest distance was 60 km and the furthest distance was 300 km. The earthquake fault line of Sabah concentrate around area of mount Kinabalu and Lahad Datu. There are more than hundreds of fault lines, however only few of them are active currently. The highest peak ground acceleration (PGA) being recorded at Sabah was at Kudat with value of 0.15g. Unfortunately, many designers or building engineers have ignored earthquake force in their structural calculation for single storey building. However, single storey building always experience cracks and damages even collapse when earthquake occurs. Therefore, a protection system needs to be introduced to avoid these tragedies from happening. There are many methods in designing a building which is earthquake resistance. Base isolation is one of them.Base isolation is a simple method to minimize the transmission of horizontal acceleration generated by earthquake to the superstructure of a building. The reduction in acceleration is important in seismic design to avoid the collapse of a building (Alberto Parducci, 1999). The main idea of base isolation is to lengthen the vibration period of a building structure (with higher damping), in order to reduce the base shear. In the presence of seismically base-isolated system which has low horizontal stiffness and high vertical strength, the superstructure and the foundation of a building is basically separated apart. In other words, the horizontal ground motion will not impose a great impact to the building. Seismic base isolator plays an important role in energy dissipation by using damping as well as to increase the fundamental time period of a structure subsequently bypass the resonance. As a result of the structures' period of vibration is increased beyond that of the earthquake the seismic acceleration response is reduced concurrently as shown in Figure 2 (Skinner, 1993). The elastic layer with low lateral stiffness and high vertical stiffness is acting as a separator between the superstructure and the foundation to avoid earthquake forces. (Clark, Peter W., Masahiko Higashino, and James M. Kelly. 1996). According to Alla (2016), many vibration control methods have been developed such as passive, active, semi-active and hybrid vibration control. Base isolation is a type of passive vibration control which will keep the building to remain elastic during

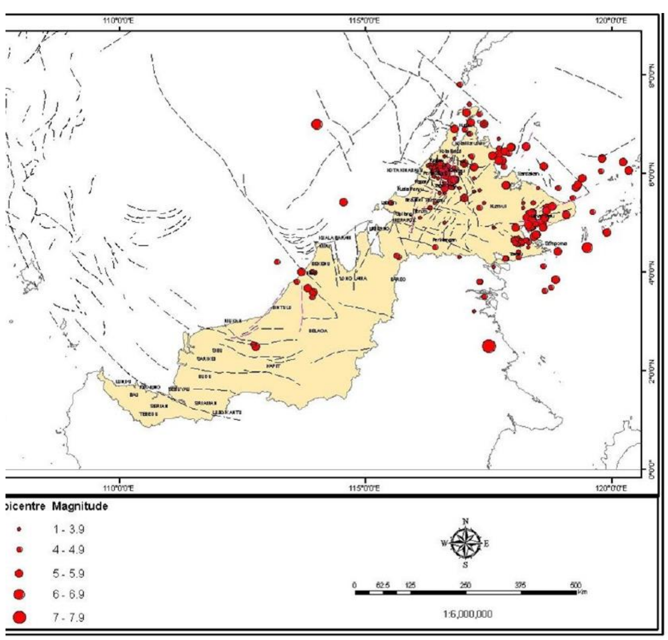

Figure 1 Earthquake events in Sabah, Malaysia

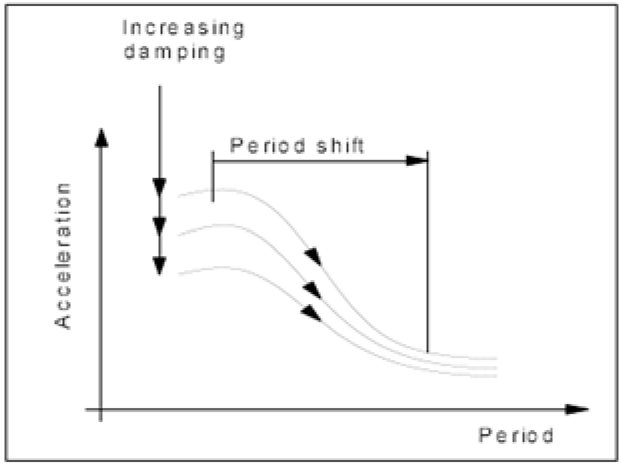

Figure 2 Acceleration response spectrum

earthquake events and lower its fundamental frequency compared to frequency of fixed base and dominant frequencies of ground motion. Rubber isolators have been widely used in the field of vibration and noise control due to their characteristics as compact structure and high damping ratio (SUN De-wei. et, 2011). Tire is a type of synthetic rubber which has low density, high hydraulic conductivity, low thermal conductivity and high shear strength at large strain. Tire has good elasticity properties and widely used in engineering projects. Recycled Tire Isolator (RTI) is a model designed as passive vibration control system using low cost material which is used tire. As such, the affordable RTI has high potential to be adopted as isolator for single storey residential buildings. In this research, RTI is tested in laboratory under a few experiments to investigate its characteristics and properties. There are various experimental studies have been carried out by researchers to investigate the mechanical and dynamic behavior of isolator such as axial compression test, inclined compression test, reverse cyclic load test or hysteresis damping test, dynamic load test, free vibration load test and shaking table test. Huma Kanta Mishra (2012) performed compression test on unbonded six layers scrap tire rubber pads measuring 100mm x 100mm or known as STRP-6. The maximum vertical load recorded was 91.9kN or 9.19MPa in vertical pressure resulting in maximum vertical displacement of 12mm. This result has proven that multilayers of scrap tire rubber pads could sustain vertical load of approximate 10 tones and sufficient to support a designed column of a single storey building.

3.0 METHODOLOGY

Recycled tire is the raw material in the fabrication of RTI. For a complete recycled tire, only the tread section is used and cut into small pieces in the form of pads. These pieces of tire pads were then cleaned with sand papers in order to remove the dirt. A flat and smooth surface need to be produced before adhesive was applied on to it so that the connection between each layer of tire pad is in good condition. The dimension of each RTI pad is 300 mm × 210 mm × 10 mm thick as shown in Figure 3(a) and the sample is shown in Figure 3(b). The width and length of RTI are chosen as 210mm and 300mm respectively due to the usable width of the recycled tire available is only approximately 250mm and the length of 300mm will provide a better surface area with appropriate proportion in overall dimension. A high strength adhesive is applied on both faces of each tire pad to provide a firm bonding

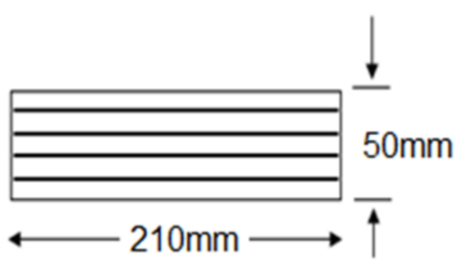

Figure 3(a) Side elevation of RTI

Figure 3 (b): RTI Sample

between the tire pads. The sample is then pressured by using G-clip for approximately 72 hours to ensure the adhesive is dried. This paper only focuses on two types of RTI which are RTI-4 and RTI-5. There are total of four layers rubber pads with 10mm thick each layer for RTI-4 and five layers of 10mm thick rubber pads for RTI-5.Two specimens each for RTI-4 and RTI-5 with the same dimension are prepared for the experimental testing. The compression test and dynamic load test were carried out using servo hydraulic MTS322 testing machine which presented in Figure 4. This machine is activated and controlled by a hydraulic power unit - SilentFlo. The sample was placed in between the top and bottom steel plate of the compression test machine that distribute the applied load across the entire surface area of both the opposite faces of RTI. A vertical hydraulic actuator then will exert vertical load onto the RTI sample by method of force control until a cracking sound was heard resulted in permanent failure of RTI. The maximum capacity of the vertical actuator is 400kN. The vertical force and the degree of vertical deformation of RTI will be measured by the LVDT transducer and high precision load cell which then be recorded in a computer attached to Servo Hydraulic MTS322. The objective of this experiment is to determine the behavior of RTI specimens under compression load, how much vertical force it can withstand and to obtain its static stiffness.

4.0 RESULTS AND DISCUSSION

4.1 Compression Test

A specimen of RTI-5 (300mm x 210mm) width with thickness of 50 mm was tested using servo hydraulic MTS322 testing machine in Lembaga Getah Malaysia (LGM). The test was static compression by force control and the criteria were based on British Standard. A controlled vertical force of 380 kN was applied on the sample gradually for five cycles. The required vertical effective stiffness of the sample was generated at the end of fifth cycle based on the equation below,

$$K_{eff} = (F_{max} - F_{min}) / \Delta_{max} - \Delta_{min} \quad (1)$$

F_{max} : maximum positive force
F_{min} : minimum negative force
Δ_{max} : maximum displacement
Δ_{min} : minimum displacement

The time data chart is presented in Figure 5 which records the displacement of RTI under a controlled force over certain time period whereas Figure 6 presents the force verses displacement graph of RTI-5.

Figure 4 Servo Hydraulic MTS322 testing machine for Compression and Dynamic Load Test

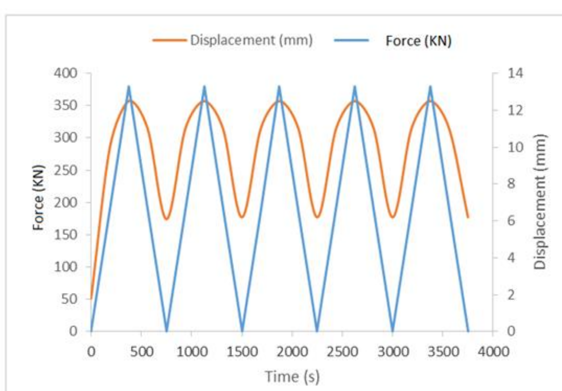

Figure 5 Displacement verses time graph for RTI-5

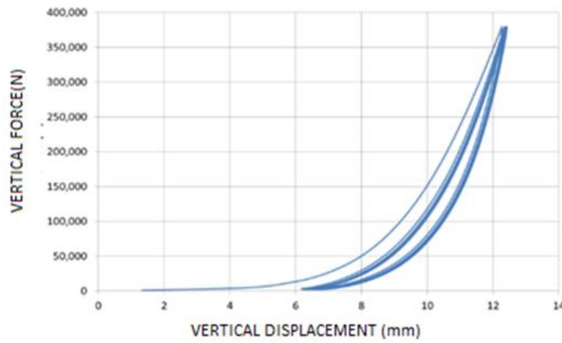

Figure 6 Vertical force verses vertical displacement graph of RTI-5

Another RTI sample, RTI-4 with thickness of 40mm was also tested under static compression to compare the result of RTI-5 in terms of vertical stiffness. The result leads to the profile in Figure 7 which shows the comparison of the vertical stiffness between RTI-4, RTI-5, Fiber-Reinforced Elastomeric Isolator (FREI) and Steel- Reinforced Elastomeric Isolator (SREI).

Based on the results in Figure 7, obviously RTI sample with lesser layer will have higher value of static stiffness compared to RTI sample with more layers. The static stiffness of RTI-4 is 118,600 N/mm which is about five times the static stiffness of RTI-5. This explains well that the more the number of layers of rubber pad, the vertical flexibility will subsequently increase. From the experiment done by other researcher, the static stiffness or vertical stiffness of commercial Steel- Reinforced Elastomeric Isolator (SREI) is 94,143.00 N/mm (G.J.Kang, B.S. Kang, 2009). The static stiffness of RTI-4 is quite close to SREI. Therefore, RTI-4 has great potential to be used as base isolator replacing SREI which is more expensive in term of fabrication cost. However, the vertical stiffness of Fiber-Reinforced Elastomeric Isolator (FREI) is only 34,813.00 N/mm which is quite similar to the static stiffness of RTI-5. From the point of engineering, vertical stiffness indicates the rigidity of the sample and its capacity to resist vertical deformation under certain axial loads. It also results from the facts that the tensional stiffness of steel is higher than the fiber as the vertical stiffness of SREI is three times higher than that of FREI. RTI-4 which has lesser layers of tire pads is expected to be stiffer compared to RTI-5 or in other words, as the number of layer of tire pad increases, the vertical stiffness of the sample will decrease. Vertical stiffness is important to justify the total vertical load from the building that the sample can withstand both before and during the earthquake event. More samples of RTI with different number layers of tire pads will be tested in the future research to accumulate more concrete and accurate data in terms of vertical stiffness and other parameters such as horizontal stiffness. From the static compression test, the vertical deformation of RTI-5 recorded was 12.5mm under a maximum axial load of 380 kN whereas RTI-4 only deformed 10.4mm when 339 kN as maximum load was applied onto it. Again it shows that RTI-4 can resist vertical load better compared to RTI-5 because RTI-4 deforms lesser under maximum load when the cracking sound was heard.

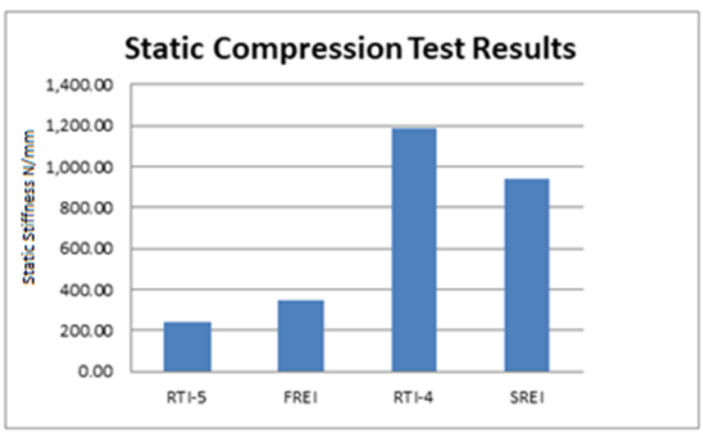

Figure 7 Static compression test results for RTI-4, RTI-5, FREI and SREI

4.2 Dynamic Compressive Load Test

Dynamic Compressive load test is a test conducted using the same machine, servo hydraulic MTS322 testing machine under amplitude of ±0.5 mm and frequency of 5 Hz. RTI is a viscoelastic material. Therefore the test machine and testing process require constant test speeds and constant dynamic frequencies. RTI as a base isolator is subjected to dynamic vertical load during the earthquake events. Therefore, it is important to study the dynamic behavior of RTI under dynamic compression. One sample each for RTI-4 and RTI-5 were tested. Dynamic parameters which are dynamic stiffness and damping ratio were recorded through this test. Figure 8 and Figure 9 display the time data chart for dynamic compressive load test of RTI-4 and RTI-5 respectively.

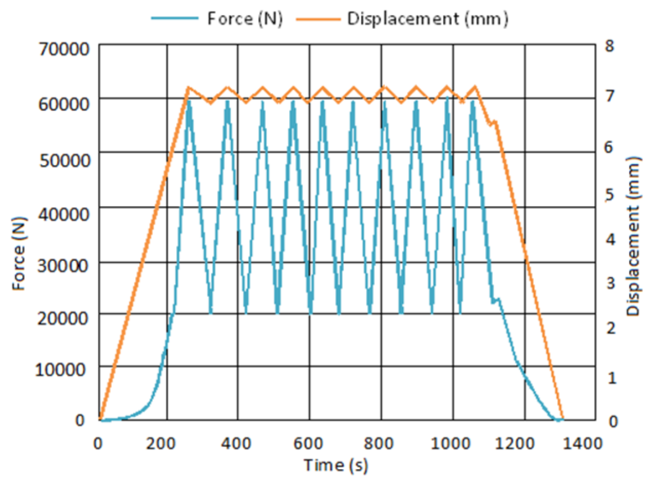

Figure 8 Time data chart for dynamic compressive load test of RTI-4

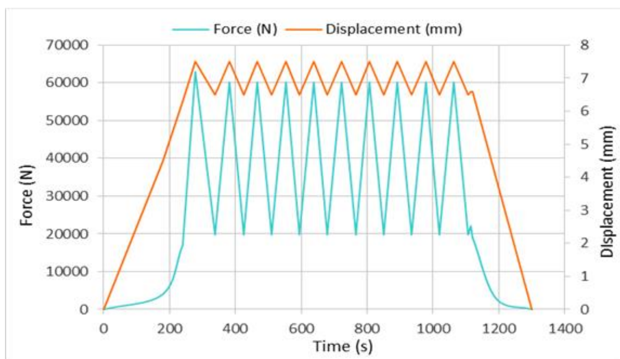

Figure 9 Time data chart for dynamic compressive load test of RTI-5

Table 1. Dynamic Compressive Load Test results for RTI-5 and RTI-4

Sample	Dimensions (mm)	Maximum Axial Load (kN)	Dynamic Stiffness (N/mm)	Damping Ratio	Damping Coefficient
RTI-5	300mm x 210mm x 50mm thick	300	44,200.00	8.3	225
RTI-4	300mm x 210mm x 40mm thick	300	83,000.00	7.2	941

From the results presented in Table 1, RTI-4 shows a higher value in terms of dynamic stiffness compared to RTI-5. This explain that the number of layer of rubber pad is one of the important factor contribute to dynamic stiffness. Damping coefficient is a material property that indicates whether a material will bounce back to its original form or return energy to a system. RTI-4 has a damping coefficient of 941 which is four times the damping coefficient of RTI-5. This means that RTI-4 is more efficient in terms of energy dissipation and able to return better to its original form compared to RTI-5. The damping ratio of RTI-4 and RTI-5 is 7.2 and 8.3 respectively. These values have a close agreement with the experimental value obtained by the researchers, Ahmet Turer (2012) and Bayezid Ozden (2006) on low cost scrap tire pads with various brands. According to their research, the optimum damping ratio for rubber bearing falls under the range between 7% and 14%. Therefore, there is a high possibility for RTI-4 and RTI-5 to replace commercial rubber bearing as base isolator for single storey building.

5.0 CONCLUSION

In this research, recycled tire which is a type of sustainable material is used to prepare the earthquake base isolator. This earthquake base isolator known as Recycled Tire Isolator or RTI with different thickness were tested under vertical compression and dynamic compressive load test. The mechanical properties and dynamic properties of these RTIs were obtained and compared within each other and also with the commercial elastomeric isolator. In terms of vertical stiffness, RTI-4 reveals a higher value than RTI-5 and this value is close with the value of commercial isolator. RTI which is a viscoelastic material is proven to have great potential to be used as base isolator for single storey building to resist earthquake force. It can withstand certain value of vertical loading as well as providing some horizontal movement due to its characteristic of elasticity. RTI as an energy absorption device is designed to absorb the energy associated with an earthquake and therefore prevent the building from being affected by this large energy. Family in poor country will need RTI to protect their houses from earthquake as RTI is economical in fabrication together with its simple installation method.

6.0 RECOMMENDATIONS FOR FUTURE WORKS

Although this research have covered the investigation works for RTI-4 and RTI-5 as earthquake base isolator, it will be more meaningful if the experimental testing could be extended to more samples with different thickness of RTI and brands of recycled tire. This will help the researcher to obtain a wider range of data on the mechanical and dynamic properties of RTI so that a more cost effective RTI with optimum performance can be developed.

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