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EFFECT OF RECYCLE TIRE ISOLATOR AS EARTHQUAKE RESISTANCE SYSTEM FOR LOW RISE BUILDINGS IN MALAYSIA

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Abstract

The purpose of this research is to investigate the effect of Recycle Tire Isolator (RTI) as earthquake resistance system for low rise buildings in Malaysia. Most of the earthquake's victims are due to the collapse of poorly designed concrete and masonry buildings. Therefore, an economical but reliable RTI is introduced to solve the problem in most of the developing countries such as Malaysia. This study focuses on the effect of RTI-5 (5 layers RTI) in protecting three stories buildings. The vertical displacement of RTI-5 was determined through static compression test. The maximum vertical displacement of RTI-5 was obtained when the specimen was monotonically loaded to failure. Finite element analysis was carried out by using ANSYS V16.0 to model the RTI-5 and the results obtained were compared to the experimental results. The dynamic stiffness and damping ratio of RTI-5 were investigated through dynamic test. The behaviour of various thickness of RTI were examined and compared with Rubber Bearing (RB) and Scrap Tire Rubber Pad (STRP).Total displacement of three stories buildings on fixed base and on base isolation were determined. The results from static compression test and finite element analysis showed that RTI-5 could sustain a vertical load of 380 kN with vertical deformation of 12.5 mm. It has been verified by finite element analysis (FEA) where both of the results achieved close agreement in terms of vertical deformation. RTI-5 and STRP have similar vertical stiffness due to the employment of same material in fabrication. However, rubber bearing is stiffer than RTI-5 due to the present of embedded steel plates. Besides, RTI-4 is stiffer than RTI-5 due to the number of layers are lesser in RTI-4. The results of dynamic test shown that RTI-5 has higher damping ratio than RTI-4. In overall, total deformation at the top floor of the three stories building is reduced by 83% via implementation of RTI in the base of the building. It has been proven that RTI can reduce the total displacement of low rise building effectively.

Keywords: Recycle tire isolator, ANSYS V16.0, Finite element analysis, Fixed base building, Base isolated building.

Nomenclatures

A	Acceleration, mm.s^{-2}
F	Frequency, Hz
s	Displacement, mm
T	Time, s

Abbreviations

FEA	Finite element analysis
RB	Rubber bearing
RTI	Recycle tire isolator
RTI-4	Four layers of recycle tire isolator
RTI-5	Five layers of recycle tire isolator
STRP	Scrap tire rubber pad

1. Introduction

An earthquake is a natural disaster that caused by the breaking and shifting of rock beneath the earth's surface. When an earthquake happens, the upper part of the building will experience inertial forces. Based on the Newton's first law of motion, the roof of a building is capable to stay in its original position although the base of the building moves in harmony with the ground. However when the walls and columns are linked to it, they will drag the roof along with them. This phenomenon is similar to the situation when the bus that a passenger standing in is moving in a sudden, the passenger's feet move with the bus, but his upper body will stay back and causing a backward motion on him [1]. Earthquake cause ground acceleration. It is useful to relate this acceleration to the acceleration due to gravity [2].

During an earthquake, the building structure is mainly affected by the lateral earthquake forces. The vertical forces are not as critical as the lateral earthquake forces [3]. In most of the countries around the world, the design engineers do not take earthquake forces as a consideration into the building design especially on the low rise buildings. However, past histories have proven that most of the low rise buildings are more vulnerable than high rise buildings to an earthquake. On September 5, 2012, an earthquake of 7.6 magnitude happened at 60km from the town of Liberia, Costa Rica, there were a total of 22 victims from this earthquake. Only two persons died from the earthquake and the rest were injured [4]. An earthquake occurred on 25th April 2015 which also known as the Gorkha earthquake struck the east of the district of Lamjung. It was the strongest and worst natural disaster occurred in Nepal [5]. Due to the frequent occurrence of earthquake, base isolation system is one of the methods to protect buildings from collapse. In 1965, the first base isolated structure in the world, i.e., the Pestalozzi primary school building was constructed in Macedonia. There were a total of 54 rubber isolators installed in the base of the building [6]. There are many types of base isolator such as Frictional Pendulum Sliding (FPS) Bearing, Laminated Rubber (Elastomeric) Bearing, etc. An extensively used isolator which is Steel-reinforced elastomeric isolator is expensive and heavy [7]. Recycle tire isolator (RTI) is proposed as a base isolation system for low rise buildings due to its characteristic and some similarities to other base isolation system to minimize the deformation of building caused by an earthquake.

The main purpose of this study is to investigate the effect of RTI as earthquake resistance system on low rise building. The first objective of this paper is to compare the vertical displacement of RTI due to the effect of vertical load between laboratory experiment and finite element analysis. The second objective is to determine the horizontal displacement of RTI due to the lateral earthquake forces through ANSYS V16.0. The third objective is to determine the dynamic stiffness and damping ratio of RTI through dynamic load test.

2. RTI-5

2.1. Components

Recycle tire is the main element in the fabrication of RTI-5 samples. Only the tread sections of tires were used to prepare the samples. Dunlop contact adhesive glue was applied in order to ensure that each layer of tire pads was bonded strongly.

2.2. Samples preparation process

Tread section of recycle tire was cut and divided into small pieces of tire pads with the dimension of 300 mm × 210 mm × 10 mm as shown in Fig. 1(a). The tire pads were stacked to five layers and Dunlop contact adhesive glue was applied on the top and bottom of each tire pad. Then the samples were put under pressure for 24 hours to make sure the layers stacked well. Fig. 1(b) shows the final product of RTI-5 sample.

Fig. 1(a). Sample of RTI.

Fig. 1(b). Sample of RTI.

2.3. Vertical load calculation

Three stories building was designed as vertical loading on RTI. Figure 2 shows a three stories residential building with dimension of 6 m length × 3 m width × 9 m height. The design live load is 1.5 kN/m^2 for the flooring (similar for all floors) based on BS 6399. The loading calculation for three stories residential building is shown in Appendix A.

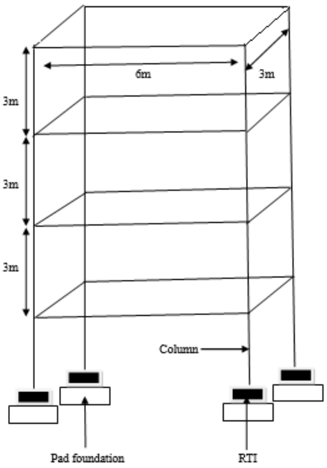
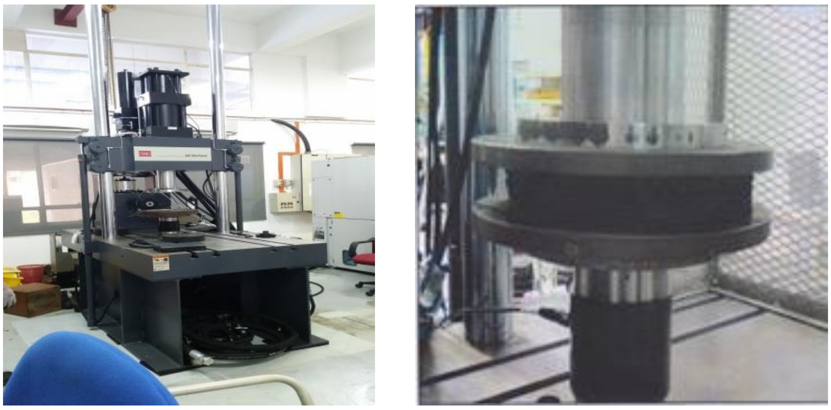


Fig. 2. Design of three stories building.

3. Results and Discussions

3.1. Static compression test

One sample of RTI-5 with dimension of 300 mm length × 210 mm width × 50 mm thick (10 mm per layer for five layers) was tested using static compression test based on British Standard. A servo hydraulic MTS322 testing machine and Multi-Purpose Testware program was used as shown in Fig. 3(a) and 3(b).



(a) Servo Hydraulic MTS322. (b) Sample under compression.

Fig. 3. Overview of test setup.

In the static compression test, the vertical force is controlled at 380 kN for five cycles. The vertical stiffness of RTI-5 was determined at fifth cycle. Vertical stiffness of RTI-5 is the rigidity of RTI-5, the extent which it resists deformation in response to an axial load. Figures 4(a) and 4(b) show the time data chart for static compression test of RTI-5 and load-deflection curves of RTI-5 while Table 1 shows the result of static compression test of RTI-5. From Table 1, it shows the vertical stiffness of RTI-5 is 41,307.95 N/mm. Based on Fig 4(b), it shows RTI-5 deformed vertically about 12.5mm when a maximum axial load of 380 kN was applied on top of it. As the axial load applied on top of RTI-5 increased, the vertical deformation increased as well.

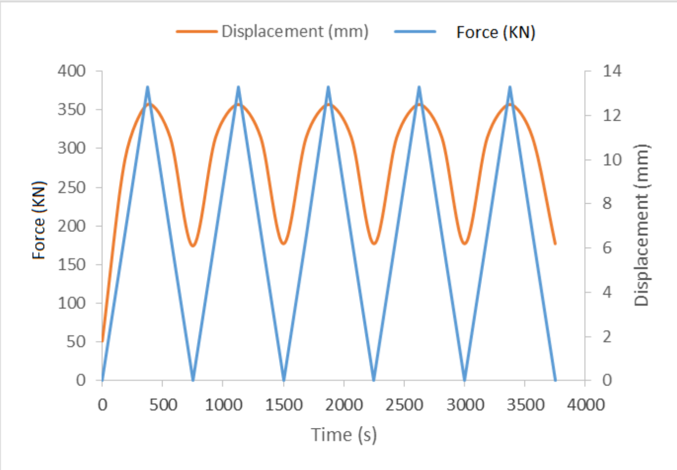


Fig. 4(a). Displacement verses time graph for RTI-5.

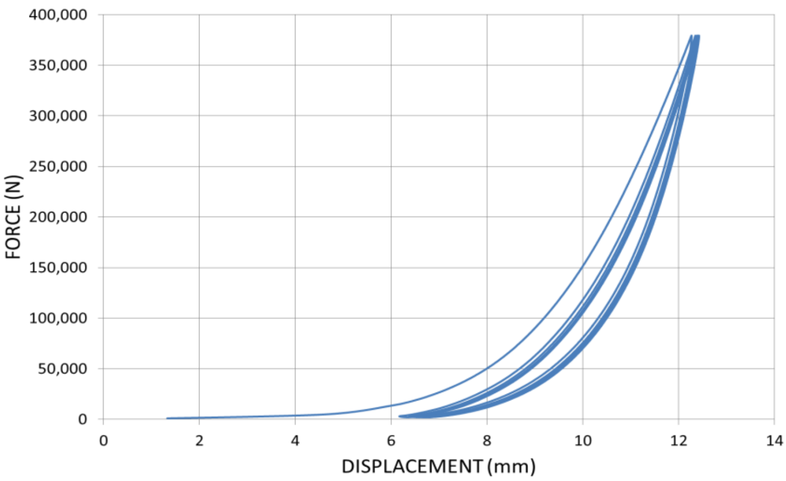


Fig. 4(b). Force verses displacement graph of RTI-5.

Table 1. Result of static compression test for RTI-5.

Sample	No. of Layers	Dimensions (mm)	Static Stiffness (N/mm)
RTI-5	5	300 (L) × 210 (W) × 50 (T)	41,307.95

3.1.1. Comparison of RTI-5 with other types of isolator in static compression test

As shown in Table 2, RTI-5 had a lower vertical stiffness than RTI-4. Thickness is one of the factor which affect the vertical stiffness of RTI sample. As compared to RB of almost similar thickness, RB has higher vertical stiffness than RTI-5. This is because RB contains multiple layers of horizontal steel plates with thicker dimensions. Different material used to manufacture RB and RTI-5 could be another factor which **affects** the vertical stiffness. As compared to STRP, RTI-5 is stiffer than STRP. This could be due to STRP sample is unbonded. Hence, RTI-5 could withstand a higher maximum axial load than STRP sample although it is thinner than STRP.

Table 2. Static compression test results for RTI, RB and STRP.

Sample	No. of Layers	Dimensions (mm)	Static Stiffness (N/mm)
RTI-5	5	300 (L) × 210 (W) × 50 (T)	41,307.95
RTI-4	4	250 (L) × 180 (W) × 40 (T)	123,637.02
RB	1	400 (L) × 350 (W) × 63 (T)	1,233,010.00
STRP	6	100 (L) × 100 (W) × 72 (T)	20,699.35

3.2. Finite element analysis for RTI-5

Four similar RTI-5 models of rubber material with dimensions of 300 mm length × 210 mm width × 50 mm thick were analyzed in finite element analysis using ANSYS V16.0. The behavior of the RTI-5 models were analyzed when a fixed vertical load of 380 kN (maximum vertical force of the machine) with various lateral loads were applied on them. The actual column load from the calculation is only 325.7 kN which is shown in Appendix A. The boundary condition for the top and bottom of the model is defined as fixed. RTI-5 is positioned between the column and foundation. Based on the results obtained as shown in Table 3, all four RTI-5 models have a constant vertical deformation of 11.8 mm as the vertical load that applied on the top center of them was constant. However, the horizontal displacement of RTI-5 models increased gradually when the lateral load increased from 10 kN to 30 kN. RTI-5 deformed horizontally about 5.7 mm when it was subjected to a lateral load of 10 kN. As the lateral load increased to 20 kN and 30 kN, the horizontal deformation was 9.3 mm and 16.6 mm respectively. RTI-5 seems to be out of shape when subjected to a lateral load of 30 kN.

Table 3. Vertical and horizontal displacement of RTI-5 at various horizontal load.

RTI Model	Vertical Load (kN)	Horizontal Load (kN)	Vertical Displacement (mm)	Horizontal Displacement (mm)
1	380	0	11.8	0
2	380	10	11.8	5.7
3	380	20	11.8	9.3
4	380	30	11.8	16.6

3.3. Dynamic load test for RTI-5

One sample of RTI-5 with dimension of 300 mm length × 210 mm width × 50 mm thick was used in dynamic test on a servo hydraulic MTS322 testing machine. The test was conducted with amplitude of ±0.5 mm at frequency of 5 Hz through displacement-controlled loading. Dynamic parameters such as dynamic stiffness, damping coefficient and damping ratio were determined. Figure 5 shows the time data chart for dynamic test of RTI-5 while Table 4 shows the results of dynamic test for RTI-5. From Table 4, it shows that dynamic stiffness of RTI-5 was 40,357.28 N/mm with a damping ratio and damping coefficient of 8.89 and 224.94 respectively (value generated from the testing machine). Basically damping coefficient is a material property that indicates whether a material will bounce back or return energy to a system. With a damping coefficient of 224.94, RTI-5 managed to diminish the response, swallow the earthquake energy and reduce the undesired reaction of low rise building.

Based on Fig. 5, RTI-5 underwent dynamic load test for 10 cycles. The total excitation time for 10 cycles was 1300 s. The excitation time of first and last cycles were longer because the load applied was started at zero and increased gradually to 63 kN. RTI-5 was monotonically loaded to 7.5 mm vertical displacement which results in equivalent axial load of 63 kN. Then it was monotonically unloaded to 6.5 mm vertical displacement which results in equivalent axial load of 18 kN. From the average results that obtained from these 10 cycles, RTI-5 was deformed vertically about 7.5 mm when an average axial load 63k N was applied on it under the conditions of amplitude ±0.5 mm at frequency of 5 Hz. The optimum range of damping ratio for rubber bearing is between 7% and 14%. Therefore, RTI-5 had a potential to be used as a low cost base isolator because it has a damping ratio of 8.89 which within the optimum range of damping ratio for rubber bearing.

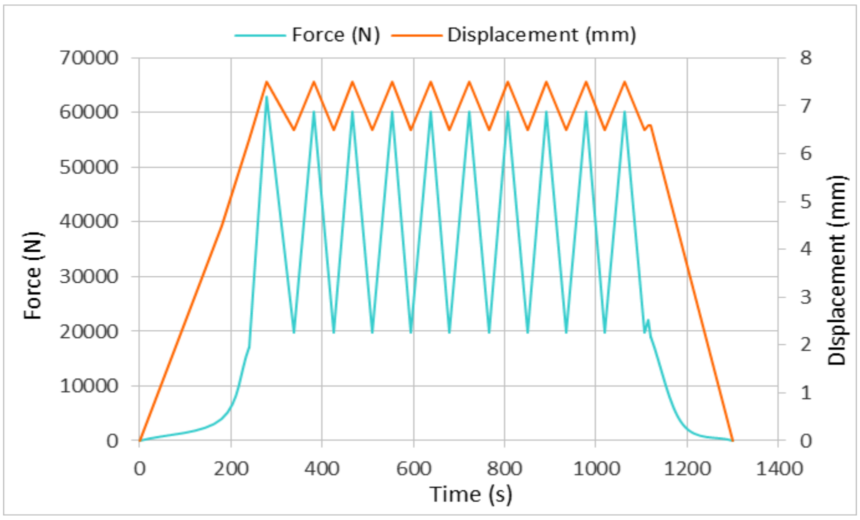


Fig. 5. Time data chart for dynamic test of RTI-5.

Table 4. Results of dynamic test for RTI-5.

Sample	No. of Layers	Dimensions (mm)	Dynamic Stiffness (N/mm)	Damping Ratio	Damping Coefficient
RTI-5	5	300 (L) × 210 (W) × 50 (T)	40,357.28	8.89	224.94

3.3.1. Comparison of dynamic test results between RTI-5 and RTI-4

From Table 5, it shows that RTI-5 has a lower dynamic stiffness than RTI-4 which is about halves the dynamic stiffness of RTI-4. In terms of resisting axial load, RTI-5 will be more efficient as it is thicker. However, RTI-5 has a higher damping ratio than RTI-4. This is because the dynamic stiffness of bearing is linearly decreases as the number of tire layer increases. The decrease of stiffness with increasing number of layers is similar to the behavior of common elastomer isolators. Besides, increase in applied axial load would decrease the damping ratio of rubber bearing [8]. Damping ratio of RTI may be related with the friction between tire layers. This shows that when a higher axial load applied on the RTI, the frictional force between layers increases, preventing layers from sliding on each other and causing smaller amount of energy dissipation which results in lower damping ratio. Hence, it could be concluded that RTI-4 has a higher dynamic stiffness and lower damping ratio than RTI-5.

Table 5. Dynamic 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	300 (L) × 210 (W) × 50 (T)	60.4	40,357.28	8.89	224.94
RTI-4	250 (L) × 180 (W) × 40 (T)	105.0	83,101.17	7.18	941.19

3.4. Comparison of top floor displacements between fixed base and base isolated building with RTI

A comparison of top floor displacements between fixed base and base isolated building with RTI has been carried out through finite element analysis as shown in Table 6 and Fig. 6. This analysis was carried out based on the time history data of Lahad Datu, Sabah earthquake with a magnitude of 5.8 [9]. The top floor displacements for fixed base and base isolated building with RTI at various time intervals are shown in Figs. 7(a) to 7(e) and Figs. 8(a) to 8(e). Based on Table 6, fixed base building deformed 2.4 mm while base isolated building with RTI deformed 0.4 mm at 5 s. The deformation is highest at this stage due to the acceleration of Lahad Datu earthquake was highest at this period. At 10 s, the top floor displacements for fixed base and base isolated building with RTI are 1.8 mm and 0.3 mm respectively. At 15 s, the top floor displacements declined to 1.3 mm for fixed base and 0.2 mm for base isolated. At 20 s, the top floor displacements further declined to 0.9 mm for fixed base and 0.15 mm for base isolation. Figure 6 shows the declination of top floor displacements for fixed base and base isolated building with RTI which started at 5 s and eventually fall to zero at 30 s. This is because the accelerations of earthquake decrease to zero between the periods of 5 s and 30 s.

From the results shown, it is clearly seen that RTI able to minimize earthquake forces effectively and fairly redistributed over the whole building. This could be due to the feature of RTI which is laterally flexible and being stiff vertically in order to resist the earthquake forces while still supporting the weight of superstructure. The base isolated building act as a rigid body with large deformations or displacements restricted by the RTI. Based on the previous research on the comparison of top floor drifts and base shear between four stories of fixed base and base-isolated building, the inter-story drift at the top of base-isolated building is reduced with approximately 81% compared to fixed base building [10]. It could be concluded that by implementing RTI onto low rise building, the maximum deformation of the building at the top floor will be reduced by approximately 83% compared to the fixed based building. Therefore, RTI is suitable to be used as a base isolation device to resist medium magnitude earthquake for low rise building. The imposed load for low rise residential buildings is calculated based on 1.5 kN/m^2 [11].

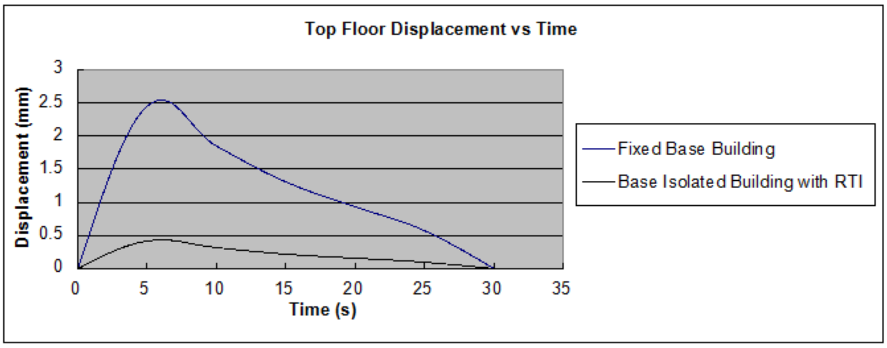
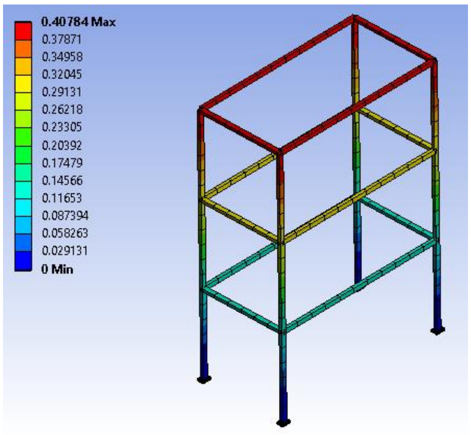


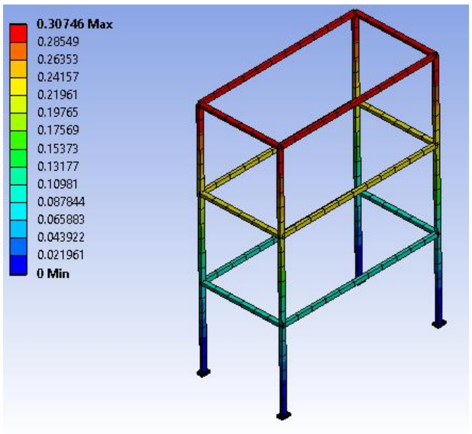
Fig. 6. Comparison of top floor displacement between fixed base and base isolated building with RTI.

Table 6. Comparison of top floor displacements at various time.

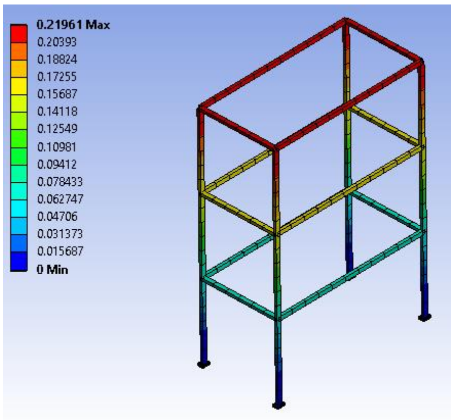
t (s)	f (Hz)	a (mm/s^2)	Fixed Base Building s (mm)	Base Isolated Building with RTI s (mm)	Reduction of Top Floor Displacements (%)
0	0	0	0	0	0
5	10	3188.3	2.4481	0.4078	83.34
10	8	2403.5	1.8455	0.3075	83.31
15	6	1716.8	1.3182	0.2196	83.34
20	4	1226.3	0.9416	0.1569	83.34
25	2	735.8	0.5650	0.0941	83.35
30	0	0	0	0	0



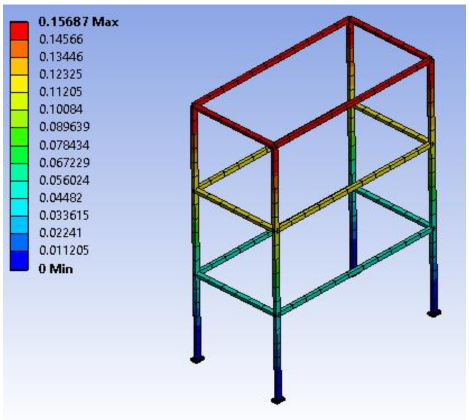
(a). Deformation of base isolated building with RTI at 5 s.



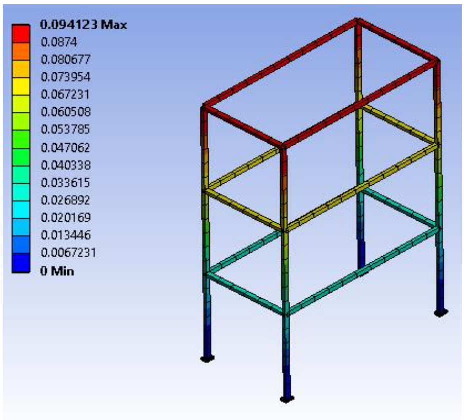
(b). Deformation of base isolated building with RTI at 10 s.



(c). Deformation of base isolated building with RTI at 15 s.

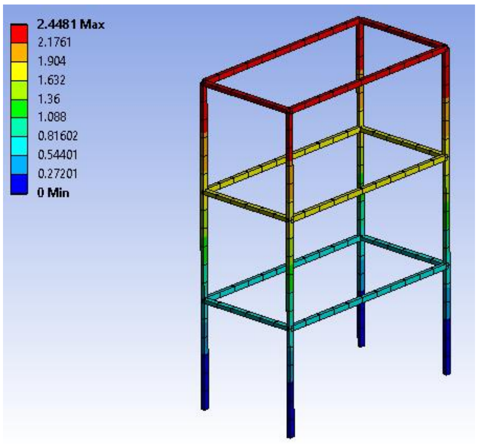


(d). Deformation of base isolated building with RTI at 20 s.

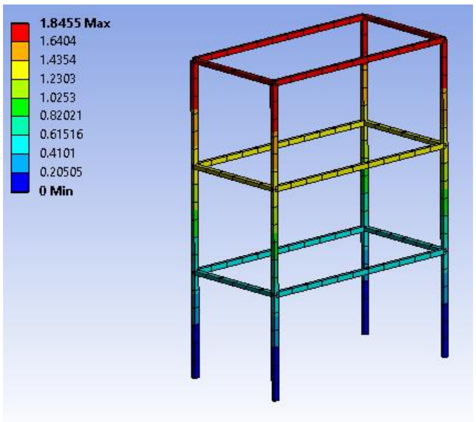


(e). Deformation of base isolated building with RTI at 25 s.

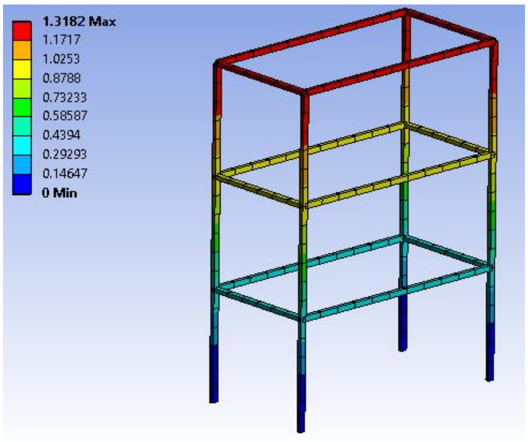
Fig. 7. Simulation with ANSYS V16.0 (with RTI)



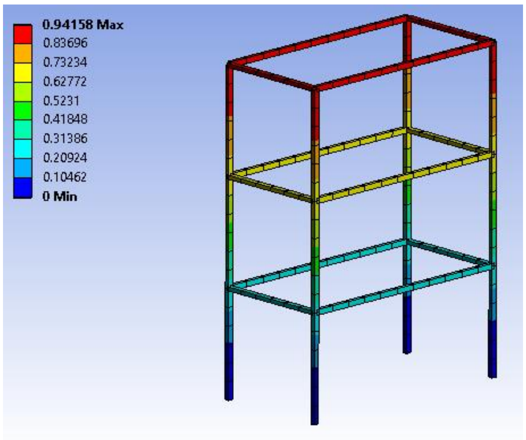
(a). Deformation of fixed base building at 5 s.



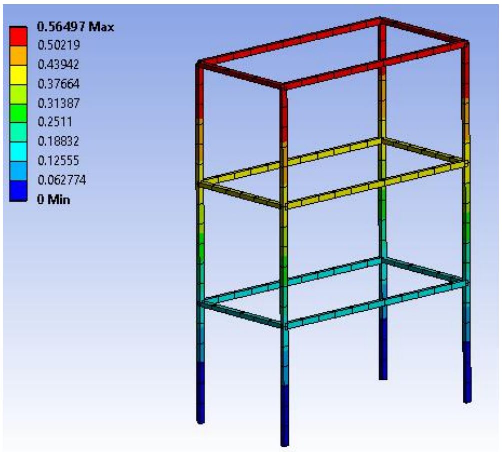
(b). Deformation of fixed base building at 10 s.



(c). Deformation of fixed base building at 15 s.



(d). Deformation of fixed base building at 20 s.



(e). Deformation of fixed base building at 25 s.

Fig. 8. Simulation with ANSYS V16.0 (without RTI).

4. Conclusions

Basically, it is obvious that the objectives of this study have been achieved. The RTI sample deformed 12.5 mm when a maximum axial load of 380 kN was applied in the static compression test. In finite element analysis, the RTI sample showed deformation of 11.8 mm under maximum axial load of 380 kN. It showed that the difference of vertical deformation between laboratory experiment and finite element analysis was within the acceptable range which is about 5.6%. Hence, the results from laboratory experiments in agreement with finite element analysis. In finite element analysis using ANSYS v16, lateral forces of 10 kN, 20 kN, and 30 kN were applied at the side of the RTI model with a fixed vertical load of 380 kN. The model showed deformation of 5.7 mm when the lateral force is 10 kN. However, the horizontal deformation increased to 9.3 mm and 16.6 mm with lateral forces of 20 kN and 30 kN respectively.The shape of RTI starts to change when the lateral load increased to 30 kN. From the comparison of top floor displacements between fixed base and base isolated buildings with RTI, the result showed that RTI has successfully reduced the top floor displacement of low rise buildings by 83% compared to fixed base building. Therefore, RTI is suitable to be used as a base isolation device to resist medium magnitude earthquake for low rise building. Overall, the results of this research show that RTI is suitable to act as a low cost earthquake base isolator which is designed for low rise buildings. As compared to other types of base isolators such as synthetic rubber bearing, lead-plug bearing and damper, the manufacturing cost of RTI is relatively low.

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Appendix A: Assumptions

Beam size	= 200 mm × 400 mm
Column size	= 200 mm × 400 mm
Slab thickness	= 150 mm
Height of each floor	= 3,000 mm
Brickwall	= 2.6 kN/m^2

3 Stories Residential Building

Dead load:	
Self-weight of beam	= (0.2 × 0.4)m^2 × 24 kN/m^3 × (3x2+6x2)m
	= 34.6 kN
Self-weight of column	= (0.2 × 0.4)m^2 × 3m × 24kN/m^{3}x16
	= 92.2 kN
Self-weight of brickwall	= 3 m × 3m × 2.6kN/m^{2}x6 + 2.6x3x3x6
	= 421.2 kN
Self-weight of slab	= 4x 6x3x0.15m × 24kN/m^3
	= 259 kN
Total dead load	= 34.6 kN +92.2 kN + 421.2 kN + 259 kN
	= 807 kN
Live load:	
Design live load	= 1.5kN/m^2
Live load on slab	= (3x6 × 1.5x4) m^2
	= 108 kN
Total design load	= 1.4×807 + 1.6×108
	= 1302.6 kN
Total load per column	= 325.7 kN