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Comparative Analysis of Tire-Based Base Isolation Techniques in Six-Storey Building by Simulation

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Abstract:

In light of all the ongoing seismic activity and its persistent threat of destructive earthquakes, research and development efforts to explore innovative and sustainable solutions for earthquake-resistant infrastructure are made worldwide. Low-cost novel materials such as rubber were utilized and found to be effective and suitable for low-rise buildings and developing countries. In this paper, three tire-based base isolation techniques, namely Layer-Bonded Scrap Tire Rubber Pads (STRP), Geometrically Modified Recycle Tire Bearing (RTB) Floor Isolation System, and Layer of Rubber Tire Sheet in between Steel Plates, are analyzed to compare their effectivity and determine which is the most optimal technique. Furthermore, the researchers aimed to investigate the applicability of the said tire-based base isolation techniques in mid-rise buildings. Four simulated building samples with different base conditions, which include isolated and fixed bases, are analyzed. The modeling of the methods and six-story building took place in Solidworks. At the same time, the non-linear time history analysis was run in ANSYS Workbench to evaluate the parameters which are total deformation, total acceleration, shear stress and equivalent elastic strain. Upon subjecting the models to the same lateral force and ground motion, the simulation did not proceed due to excessive deformation. Frictionless Support was added on top of the tire-based isolation to restrict the crushing along the y-axis. After that, numerical data showed significant improvements on all parameters except shear stress compared to fixed base building. Among all parameters, the layer of rubber tire sheet between steel plates model was determined to be the most optimal technique.

Keywords **—Time History Analysis, Tire-Based Base Isolation, Transient Structural Analysis**

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I. INTRODUCTION

In the Philippines, frequent and powerful earthquakes, often exceeding a magnitude of 8.0, result in extensive destruction across areas spanning hundreds of kilometers, leading to significant damage and devastation. Due to the unique tectonic conditions in the country, it experiences a higher frequency of earthquakes than the global average. Since 1950, these seismic events have tragically claimed the lives of more than 4,800 individuals due to their immediate impacts. Additionally, there have been 23 earthquakes that triggered subsequent tsunamis, resulting in further loss of life and causing additional damage. The Philippines continues to encounter multiple earthquakes daily, with magnitudes ranging from 1.4 to 4.7, occurring in various regions of the country [1]. Earthquakes harm both horizontal and vertical designs, especially reinforced concrete structures. Numerous RC systems were made to support just gravity loads. They are areas of strength for neither ductile enough to exhibit a global failure mechanism by cyclic stacking conditions. Due to deficient cross-over support "strong column or weak beam" designs, these designs regularly have non-flexible support at the pillar segment joint regions [2].

In light of the ongoing seismic activity and the persistent threat of destructive earthquakes in the Philippines, there is an urgent imperative for research and development efforts to explore innovative and sustainable solutions for earthquake-resistant infrastructure. The potential utilization of scrap tires as a novel material for seismic base isolation warrants thorough investigation. As a readily available waste material with properties resembling traditional seismic isolators, scrap tires offer a promising avenue to enhance the resilience of mid-rise structures in earthquake-prone regions like the Philippines. To effectively safeguard lives and infrastructure while addressing the environmental challenge of tire disposal, it is crucial to embark on comprehensive research endeavors that assess the viability and effectiveness of tire-based isolation systems, ultimately contributing to both earthquake resilience and sustainable waste management practices in the region.

Over the past two decades, there has been a growing awareness of the significant environmental threat of accumulating scrap tires in waste disposal areas. This issue has prompted extensive research within civil engineering to investigate the potential applications of scrap tires in various construction and infrastructure projects.

Scrap tires, a readily available waste material commonly found in disposal sites, pose a unique challenge due to their non-biodegradable nature, making recycling and disposal difficult. Within radial car tires, the rubber pads reinforced with wire mesh, resembling the steel or fiber-reinforced elastomer or laminates made from natural rubber used in seismic response control systems, namely Steel-Reinforced Elastomeric Isolator and Fiber-Reinforced Elastomeric Isolator. However, more research studies are needed to assess their effectiveness in mitigating seismic responses as an alternative to traditional SREIs and FREIs [3].

Earthquake-resistant design strategies aim to safeguard structures from widespread damage by permitting controlled damage in predetermined structural components. An alternative approach to earthquake protection in civil engineering involves the application of structural control methods. Seismic base isolation represents a passive structural control technique that, in essence, extends the inherent natural period of structures while augmenting damping characteristics within isolated systems. This serves to mitigate the transfer of ground motion forces to the superstructure.

Software as the primary tool in simulation about base isolation refers to the set of instructions that are generated through computers or computer programs to execute the tasks needed. The software application or computer program wherein a computer program is launched to support the application to accomplish the activity. In this study, the leading software used as a program pre-determines the importance of base isolation in modern days [4]. It is ANSYS, which provides an understanding of how a specific product, such as building a specific base isolator, will work or not in natural conditions. Furthermore, the software focuses on the analysis and design of multi-story buildings. Specifically, the analysis of the six-storey building [5].

II. METHODOLOGY

The final goal of this research was to find which of the three-base isolation techniques which became the most optimal for a six-story essential building. To achieve this, the researchers have formulated a plan divided into four phases, as shown in the figure below: data collection of material properties, characteristics of each tire-based base isolation technique and structural plan of a six-story essential building; modeling the structural plan in ANSYS; simulation of the model as if subjected to seismic events; statistical analysis; and interpretation of the resulting data.

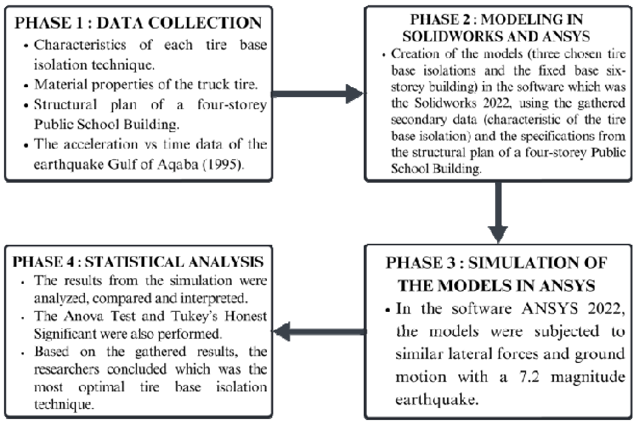


Fig. 1. Methodological Framework

A. *Phase 1: Data Collection*

The properties, dimensions, and characteristics of each material were required before proceeding to the proper modeling of the three tire-based base isolation. The study aimed to determine the most optimal technique incorporated or installed in a six-story building using the materials and building standards from the Philippines.

The specific tire used as the basis for the geometrically modified tire base isolation was TR685 for light truck vehicles with a size of 245 or 70R19.5 and an overall diameter of 33 inches base from Triangle Tires Philippines Website.

Every year, approximately one billion tires become unusable. In the Philippines, where there are nearly 10 million registered vehicles, about 10 million tires reach the end of their lives annually. On average, tires are only usable for 2 to 4 years. The use of end-of-life tires as base isolation substances offers a long-term and cost-effective alternative to decreasing earthquake risks in building applications. End-of-life tires are reused for base isolation, giving an uncommon circumstance for enhancing strength against seismic stresses but simultaneously solving environmental issues regarding tire waste.

To perform the Time History Analysis or the Transient Structural in ANSYS, the researchers used the general material or default properties in ANSYS, which are concrete for the six-story structural building and structural steel for the base plate of the base isolation designs. Hence, these materials are used to simulate each of the base isolations together with the six-story structure. Moreover, the researchers conducted data gathering for tire rubber since it is not readily available in the software as end-of-life tire material. After collecting the required data, its property is a density of 1130 kg/m^3 using Mooney-Rivlin 2 as its parameter for its hyperelasticity. The material has a constant of 0.17 and 0.83 Mpa, which were added manually to the engineering data.

To answer the research gap, which was the application of the different base isolation techniques formulated from other countries in the Philippines, the researchers requested a copy of the Four-Storey Public School Building with 20 classrooms. The said building had a high importance factor of 1.5 as it was categorized as an essential building and a mid-rise structure. To achieve the goal of using a six-story building, the fourth floor of the plan was duplicated as the fifth and sixth floors. The total height, width and length of the whole were 20.381m, 9.9m and 55m, respectively. Lastly, the researchers gathered data from the Ground Motion Database of Pacific Earthquake Engineering Research Center. The acceleration vs time needed was from the earthquake in the Gulf of Aqaba in 1995, recorded from station Hadera with a magnitude of 7.2 to mimic the expected earthquake to occur in Marikina.

B. *Phase 2: Modeling in Solidworks and ANSYS*

The modeling of the chosen base isolation took place in Solidworks 2022 to properly follow the secondary data, which were the reference of the researchers. Each of the techniques was first sketched up, creating its shape, and then the smart dimensions to make it 3-dimensional were specified. After data collection for the design and specification of the building, the same procedure was made to create the model of the six-story public school building.

The simulation of the six-story building incorporated with tire-based base isolation in its column was performed in ANSYS using "Transient Structural," which uses Time History in analysis. The models created from Solidworks were imported to ANSYS. After that, the engineering data for concrete, steel, and tire rubber are added to the setup, defining the material properties of each.

Upon modeling the three tire-based base isolation techniques, the researchers created a total of four (4) structures subjected to the ground motion of the Gulf of Aqaba earthquake, with the ground motion being applied to the strong axis of the structure. One (1) fixed base six-story and three (3) six-story buildings with tire-based base isolation technique attached to its column. On each set, the six-story building was subjected to lateral loadings and the 7.2 magnitude earthquake data using acceleration vs. time, having a total duration of 12 seconds.

C. Phase 3: Simulation of the Models

In this phase, all four structures (fixed and isolated) were completed and ready to be tested. A total of 36 tire-based base isolations were placed in each column of the structure. In each set-up, the boundary conditions are defined, and the bottom part of the isolation is fixed to prevent the base part of samples from moving upon the application of lateral loads. Frictionless support was added on the top part of base isolation to mimic the isolator protection that prevents the building from crushing the tire-based base isolation. All simulated sample structures were subjected to similar lateral forces derived from the distributed base shear calculated by the researchers. In this study, values of total deformation, total acceleration, shear stress, and equivalent elastic strain were calculated by ANSYS (2022).

For the tire-based base isolation techniques, which failed to improve the behavior of the structure during applied acceleration vs. time data, the researchers recommended enhancing the size of the low-cost isolators to support not just low-rise buildings and providing further investigation or inquiry about the needed isolator protector.

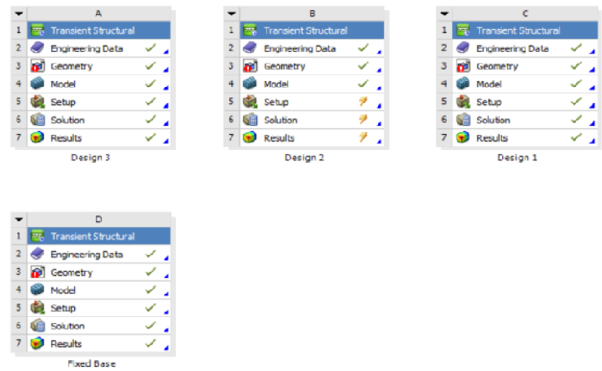


Fig. 2. Steps in ANSYS Workbench

To further explain the set-up and process of simulation using ANSYS software, the following steps were as follows:

Transient Structural. First step was the selection of analysis, time history analysis was selected to investigate the behavior of the structure. Different kinds of analysis can be selected including Explicit Dynamics, Rigid Dynamics, Modal, Response Spectrum etc.

Engineering Data. All materials used in the simulation are defined and selected in this section. Readily available data such as structural steel and concrete came from the "Engineering Data Sources" of the software while tire rubber's properties such as density and hyper elasticity which are not readily available were inputted manually.

Geometry. In this part the files of the models were imported in the software, their respective dimensions and geometric configuration are defined creating the specimen of a six-storey building with tire-based base isolation.

Model. Lastly, after creating the specimens or models the material properties of each solid structure (concrete), base plate (loads) and rubber tyre were assigned. Transforming the models into its equivalent mesh would allow the surface to perform the Time History Analysis (THA). The boundary conditions such as the base isolator are suppressed, assigning its base as fixed support to hold the specimen in place before subjecting to the lateral loads and acceleration from time history data. The analysis setting, solution and results are also part of this section. After prompting the software to solve and perform the test, numerical results such as total deformation, shear stress, total acceleration and equivalent elastic strain are readily available in the bottom screen of the software ready for export.

D. Phase 4: Statistical Analysis

After the simulation, numerical data were already gathered and ready for comparative analysis for each of the setups. The parameters in this study were the comparison of the results of the independent variable, which were the shear stress, total deformation, total acceleration, and equivalent elastic strain response of the whole structure, using different tire-based base isolation techniques attached to its columns and fixed base structure. The comparison aimed to improve the response of the structure subjected to ground motion and earthquake loads, where the ground motion is applied to the strong axis of the structure.

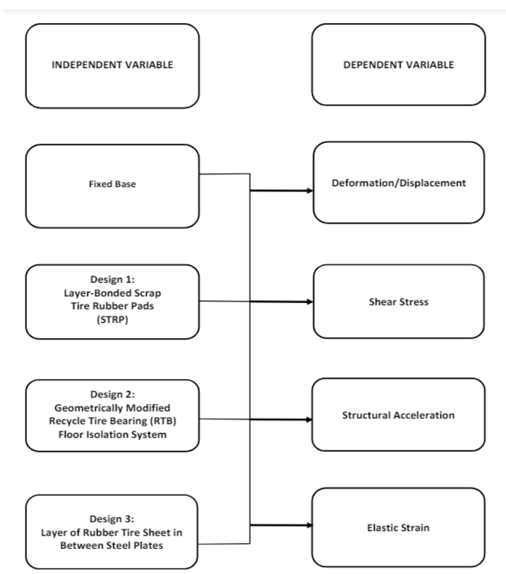


Fig. 3. Statistical Analysis

The figure shows the independent and dependent variables for multiple comparisons of the different techniques. The independent variables were the three tire-based base isolation techniques: Layer-Bonded Scrap Tire Rubber Pads (STRP), geometrically modified Recycled Tire Bearing (RTB) Floor Isolation System, Layer of Rubber Tire Sheet Between Steel Plates and fixed base. The dependent variables, on the other hand, were shear stress, total deformation, total acceleration and equivalent elastic strain.

Using tables, the researchers conducted statistical analysis to compare the results of each design in terms of the dependent variables mentioned above. The researchers compared the maximum values gathered to determine which design has the lowest maximum. Moreover, an Anova Test with a single factor was performed to find whether the results have any significant difference in their mean. Finally, the researchers also performed Tukey's Honest Significant Difference (HSD), which assessed which groups were significantly different from one another as a follow-up for the one-way ANOVA since the F-test revealed that a significant difference between groups exists.

III. RESULTS AND DISCUSION

E. Material Properties of Simulated Models

This part showed the gathered and chosen engineering data that was used in performing the Time History Analysis in Ansys Workbench. It has the specific type of rubber hyper elasticity parameters required to be defined by the software to proceed with the simulation to acquire results.

Fig. 4. Material Property of Tire Rubber used in ANSYS Workbench

The researchers used a density of 1130 kg/m^3 for the tire rubber using the Mooney-Rivlin 2 parameter as the basis for its hyper elasticity. This hyper plastic model dominated the rubber mechanics for the theory of large elastic deformation of isotropic materials. The parameter constants were 0.17 and 0.83, respectively. Upon inputting the constant, ANSYS was then filled with the material properties needed, like Poisson's ratio, in accordance with the Mooney-Rivlin theory or calculation.

The following were the utilized engineering data for the transient structural analysis feature of ANSYS Workbench.

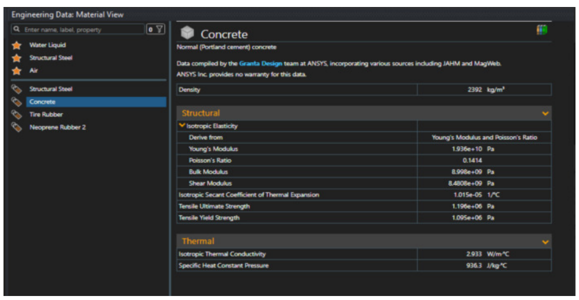


Fig. 5. Engineering Data in ANSYS Workbench

Concrete materials for structure, structural steel for base plate, the available engineering data in the software was used as shown in the figure above.

F. Time History Data used in Simulation

The researchers obtained the acceleration vs. time history data from the Pacific Earthquake Engineering Research Center database, which had over 29,000 records of earthquakes recorded from 1379 stations. Unfortunately, earthquake data from the Philippines with a magnitude of 7.2 was not available in the database. The researchers chose the 1995 Gulf of Aqaba earthquake to mimic the expected earthquake to occur in Marikina near the valley fault line.The acquired data was scaled using the ASCE 7-10 ground motion scaling procedure for Nonlinear Analysis of Buildings. Specifically, the Square Root of the Sum of the Square (SRSS) is the scaling of the data used. The time history data has a duration of 12 seconds.

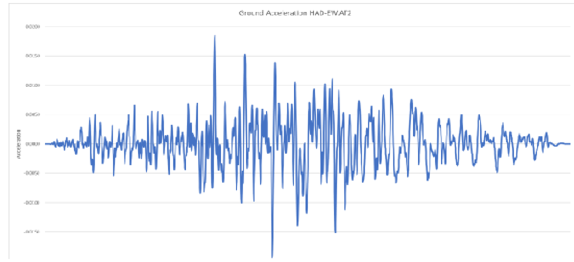


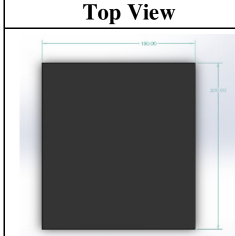
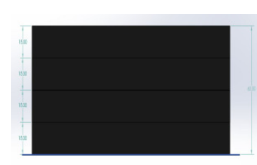
Fig. 6. Time History Data

G. Modeling in Solidworks

After creating the document, the models of the chosen tire-based base isolation technique were created. Then, the sizing of the 2-dimensional sketch was defined based on the references. The last step was making the shape and defining its dimensions. For the geometrically modified technique that retained the shape of the tire, the diameter and sizing of TR685 from Triangle Tire Philippines, which has a diameter of 33 inches, were used.

Fig. 7. TR685 Model using Solidworks

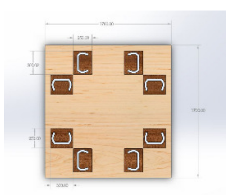
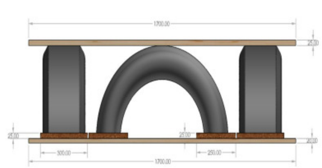
TABLE I
DIMENSIONS AND VIEW OF DESIGN 1 MODEL

Design 1: Layer-Bonded Scrap Tire Rubber Pads (STRP)	
Top View	**Front View**
	

The figure above shows the dimensions of each rubber pad being 150mmx200mm and thickness of 15mm. This model has 4 layers of rubber pads with overall thickness of 60mm.The original combining agent epoxy was not followed because in ANSYS all layers are already bound together.

Dimensions: [17]
Overall Thickness = 60mm
Each rubber pad = 150mmx200mmx15mm
Research Paper Reference: *"Seismic Floor Isolation using Recycled Tires for Essential Buildings in Developing Countries"*

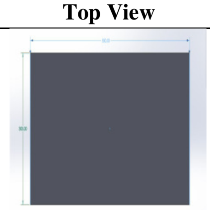
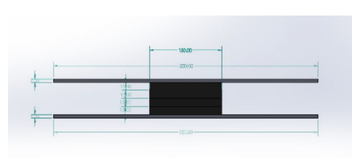
TABLE II
DIMENSIONS AND VIEW OF DESIGN 2 MODEL

Design 2: Geometrically Modified Recycle Tire Bearing (RTB) Floor Isolation System	
Top View	**Front View**
	

The top and base plate of the model are 25mmx1700mmx1700mm in size. Above the base plate are 8 embossed sections with dimensions of 20mmx250mmx300mm design to exactly fit the edge of each cut tire.

Dimensions: [16]
Top and base plate = 25mmx1700mmx1700mm
8 embossed sections = 20mmx250mmx300mm
Research Paper Reference: *"Innovative Base Isolators from Scrap Tyre Rubber Pads"*

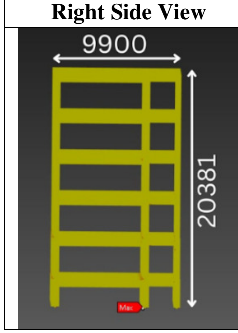
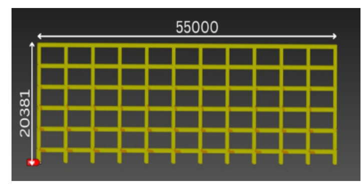
TABLE III
DIMENSIONS AND VIEW OF DESIGN 3 MODEL

Design 3: Layer of Rubber Tire Sheet in Between Steel Plate	
Top View	**Front View**
	

In this model there are four rubber pads with dimensions of 150mmx200mmx15mm. The layer of rubber pads is placed in between steel plates that are 550mmx300mmx6.35mm in size.

Dimensions: [18]
Four rubber pads = 150mmx200mmx15mm
Rubber pads in between steel plates = 550mmx300mmx6.35mm
Research Paper Reference: *"Prototype of Low Cost Seismic Isolator using Recycled Tire Sheet"*

TABLE IV
DIMENSIONS AND VIEW OF SIX-STOREY BUILDING

Six-Storey Public School Building	
Right Side View	**Front View**
 	

Based on the plan of a Four-Story Public-School Building with 20 classrooms acquired from DPWH Region III, the total height, length, and width of the building are 20.381m, 55m and 9.9m, respectively. Given that to achieve the goal of using a mid-rise building, the researchers duplicated the fourth floor to be the fifth and sixth floors.

H. Modeling and Simulation in ANSYS Workbench

After modeling the three tire-based base isolation techniques and the six-story building in Solidworks software, files are imported into ANSYS. Each method is placed at the bottom of each ground-floor column individually. Therefore, thirty-six (36) columns were created with tire-based base isolation within them.

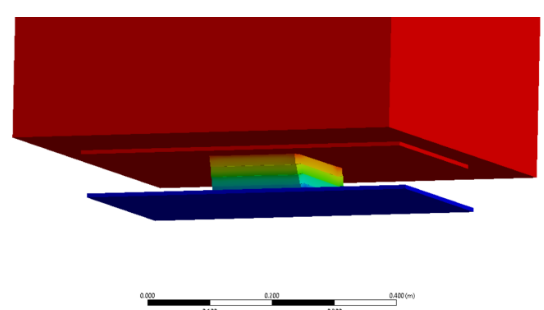


Fig. 8. Tire-Based Base Isolation below the column

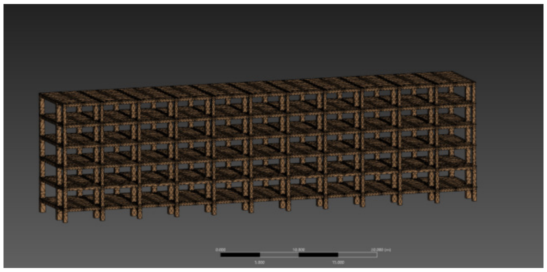


Fig. 9. Mesh of the six-story building

Before proceeding to the simulation process, acceleration vs. time history data of the Gulf of Aqaba Earthquake were imported from an Excel file to the details of acceleration in ANSYS. Moreover, the lateral forces computed are applied to the structure, as shown below. Lastly, for the solution part, total deformation, total acceleration, shear stress, and equivalent elastic strain are added before solving.

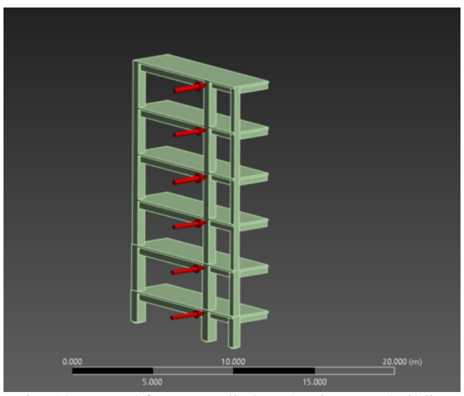


Fig. 10. Lateral forces applied to the six-story building

TABLE V
LOADING CONDITIONS CALCULATED USING NSCP 2015 LATERAL FORCE PROCEDURE

Loading Condition (Lateral Forces)	
Roof Deck	517.81KN
Fifth Floor	410.30KN
Fourth Floor	333.14KN
Third Floor	255.98KN
Second Floor	178.82KN
First Floor	101.66KN

The following lateral forces on each floor were calculated using NSCP 2015 lateral force procedure. Specifically, the Static Force Procedure of section 208.5.

I. Summary of Numerical Results from ANSYS Workbench

This section reveals the numerical data and the effect of the lateral loading applied to each building specimen. The maximum numerical results consisted of the maximum total deformation, total acceleration, shear stress and equivalent elastic strain.

TABLE VI
SUMMARY OF MAXIMUM OBTAINED RESULTS FROM ANSYS WORKBENCH

Summary of Maximum Obtained Results from ANSYS Workbench				
Building Condition	**Total Deformation (mm)**	**Total Acceleration (m/s^2)**	**Shear Stress (Mpa)**	**Equivalent Elastic Strain (m/m)**
Fixed Based	169.54	0.035781	9.411	0.0077567
Isolated (Design 1)	73.185	0.01647	14.935	0.0066928
Isolated (Design 2)	72.144	0.0014296	7.4185	0.0050785
Isolated (Design 3)	61.825	0.010919	17.928	0.0025761

The drift limit, according to ASCE 7-16, is shown in *Table 3.7 below*, based on the risk category and type of seismic forces. The allowed drift or the limit, Δa, for D, E, or F moment frame systems with seismic design categories that were divided by the redundancy factor, ρ. The drift considerations were governed and regulated by ASCE 7-16 Section 12.12.1.1.The maximum allowable drift for regular buildings is 0.7% to 2.5% of the story height, according to the IBC, and 1% to 1.5% according to Eurocode 8. It's important to consider P-delta effects and prevent pounding between structures. Additionally, thorough checks are necessary for external cladding and columns to ensure they can withstand the deflections caused by the design earthquake. The allowable story drift for the entire structure needs to be computed as detailed below:

$$Allowable\ Displacement =$$
$$0.020\ (23.381) = 0.46762m\ or\ 467.62\ mm$$

Allowable Displacement (467.62mm) > Maximum Deformation (169.54mm) [Safe]

J. Graphical Representation of the Maximum Results for Six-Story Building Obtained from ANSYS Workbench – Different Based Condition

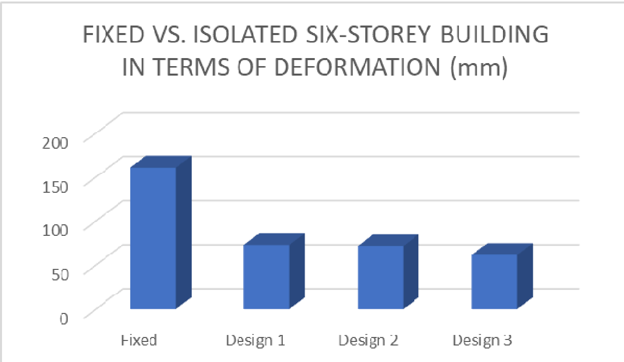


Fig. 11. Comparison between Fixed Base vs Isolated Bases with different types of Tire-based Base Isolation in terms of Total Deformation.

As shown in the figure, the fixed base obtained the highest value for total deformation, 169.54mm, followed by Design 1, 73.185mm; Design 2, 72.144 mm; and finally, Design 3, 61.825mm, which obtained the lowest value of total deformation.By comparing the results in the figure, it was concluded that in terms of total deformation, the fixed base produced the highest value while Design 3 produced the lowest value.

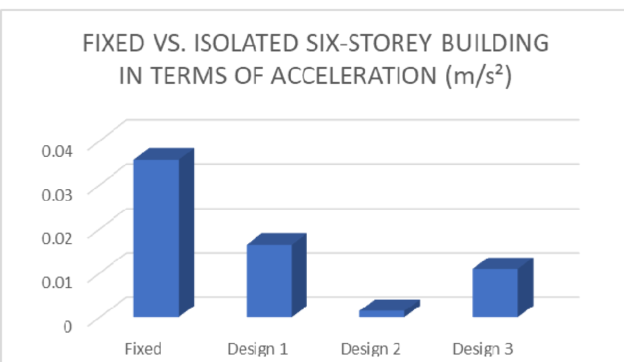


Fig. 12. Comparison between Fixed Base vs Isolated Bases with different types of Tire-based Base Isolation in terms of Total Acceleration

As shown in the figure, the fixed base obtained the highest total acceleration value, 0.035781 m/s2, followed by Design 1 with 0.01647 m/s2, Design 3 with 0.010919 m/s2, and finally, Design 2 with 0.0014296 m/s2, which obtained the lowest total acceleration value.By comparing the results in the figure, it was concluded that in terms of total acceleration, the fixed base produces the highest value while Design 2 produces the lowest value. However, due to the reduced value of the ground motion in the simulation of Design 2, Design 3 governs.

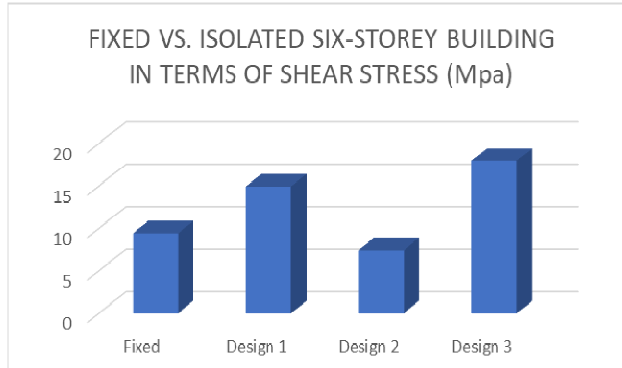
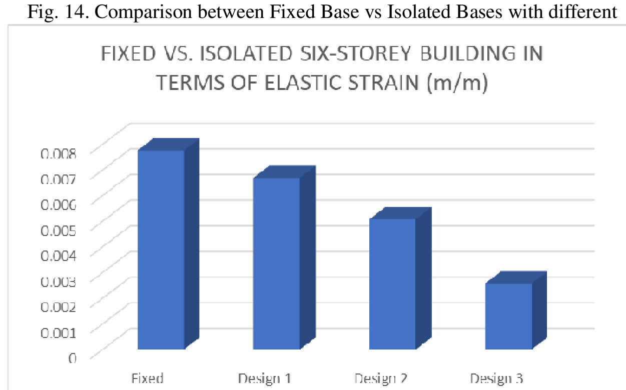


Fig. 13. Comparison between Fixed Base vs Isolated Bases with different types of Tire-based Base Isolation in terms of Shear Stress.

As shown in the figure, Design 3 obtained the highest value for shear stress, 17.928Mpa, followed by Design 1 with 14.935Mpa, fixed base with 9.411Mpa, and finally, Design 2 with 7.4185Mpa, which obtained the lowest value for shear stress.By comparing the results in the figure, it was concluded that in terms of shear stress, Design 3 produced the highest value while Design 2 produced the lowest value. Therefore, none of the tire-based base isolation techniques governs shear stress as they generated increased value when compared to a fixed base.

Fig. 14. Comparison between Fixed Base vs Isolated Bases with different



types of Tire-based Base Isolation in terms of Elastic Strain.

As shown in the figure, the fixed base obtained the highest value for equivalent elastic strain, 0.0077567m/m, followed by Design 1 with 0.0066928m/m, Design 2 with 0.0050785m/m, and Design 3 with 0.0025761m/m, which obtained the lowest value.By comparing the results in the figure, it was concluded that in terms of equivalent elastic strain, the fixed base produced the highest value, while Design 3 delivered the lowest value.

K. Line Graph Representation of the all-Maximm Results for Six-Story Building Obtained from ANSYS Workbench-Different Base Condition

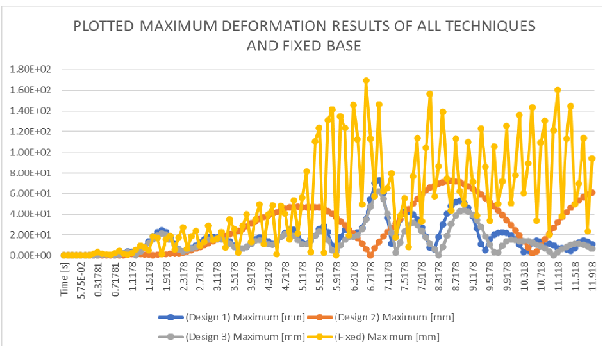


Fig. 15. Comparison of all Maximum Results between Fixed Base vs Isolated Bases with different types of Tire-based Base Isolation in terms of Total Deformation.

The figure shows all the maximum results from three techniques and a fixed base, obtained within the 12-second duration of time history data from ANSYS Workbench. Interestingly, results from fixed-based fluctuate up and down abruptly, while results from designs 1, 2, and 3 fluctuate in an illustrative manner. Based on the figure, the maximum results for fixed were comparatively higher compared to designs 1, 2, and 3. The highest maximum total deformation of 169.54 from the fixed base was obtained at 6.62 seconds. On the other hand, design 3 had the lowest maximum result, 61.825, which was received at 6.71 seconds. The line graph shows that the results of the fixed base were comparatively higher, while the results of design three were the lowest compared to all four data sources. This means that the six-story building with tire-based base isolation techniques generated lower deformation results compared to the fixed base, which was the base parameter of the comparison.

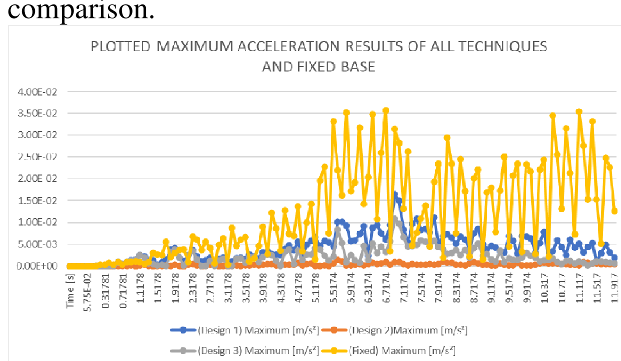


Fig. 16. Comparison of all Maximum Results between Fixed Base vs Isolated Bases with different types of Tire-based Base Isolation in terms of Total Acceleration.

The figure shows all the maximum results from three techniques and a fixed base obtained within the 12-second duration of time history data from ANSYS Workbench. Based on the figure, the maximum results for fixed were comparatively higher compared to Designs 1, 2, and 3. The highest maximum total acceleration of 0.035781 from the fixed base was obtained at 6.72 seconds. Technically, results from design 2 have the lowest value; however, due to its failure, it is already not part of the comparison. Therefore, results from Design 3 have the lowest maximum result of 0.010919, which was obtained at 7.01 seconds. The line graph shows that the results of the fixed base were comparatively higher, while the results of design three were the lowest compared to the three data sources. This means that the six-story building with tire-based base isolation techniques generated lower acceleration results compared to the fixed base, which was the base parameter of the comparison.

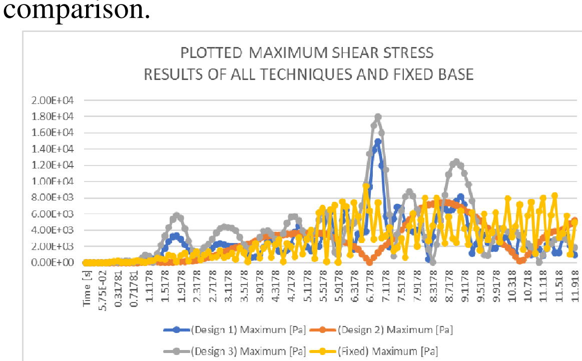


Fig. 17. Comparison of all Maximum Results between Fixed Base vs Isolated Bases with different types of Tire-based Base Isolation in terms of Shear Stress.

The figure shows all the maximum results from three techniques and a fixed base obtained within the 12-second duration of time history data from ANSYS Workbench. Interestingly, results from fixed based fluctuate up and down abruptly, while results from Designs 1, 2, and 3 fluctuate in what seems like an illustrative manner. Based on the figure, the maximum results for fixed are comparatively lower compared to Designs 1, 2, and 3. The highest maximum shear stress of 14.935 from Design 3 was obtained at 6.91 seconds. On the other hand, the fixed base has the lowest maximum result of 9.411, which was received at 6.618 seconds. The line graph shows that the results of the fixed base were comparatively lower, while the results of the fixed base were the lowest compared to all four data sources. This means that the six-story building with tire-based base isolation generates higher shear stress results compared to the fixed base, which was the base parameter of the comparison.

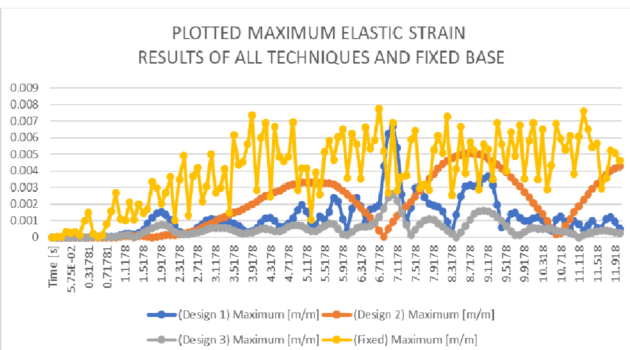


Fig. 15. Comparison of all Maximum Results between Fixed Base vs Isolated Bases with different types of Tire-based Base Isolation in terms of Total Deformation.

The figure shows all the maximum results from three techniques and a fixed base obtained within the 12-second duration of time history data from ANSYS Workbench. Interestingly, results from fixed-based fluctuate up and down abruptly, while results from Designs 1, 2, and 3 fluctuate in a somewhat parabolic manner. Based on the figure, the maximum results for fixed were comparatively higher compared to designs 1, 2, and 3. The highest maximum equivalent elastic strain of 0.0077567 from the fixed base was obtained at 6.717 seconds. On the other hand, Design 3 had the lowest maximum result of 0.0025761, which was received at 7.12 seconds. The line graph shows that the results of the fixed base were comparatively higher, while the results of Design 3 were the lowest compared to all four data sources. This means that the six-story building with tire-based base isolation generates lower elastic strain results compared to the fixed base, which was the base parameter of the comparison.

L. Percentage Difference

In this section, the percentage difference of each design compared to the fixed-based structure was presented in terms of the four parameters. This determines how different the results of each design were compared to the base parameter. The design or technique that gives the most optimal result governs, taking into consideration that the simulation of Design 2 failed. Therefore, the researchers opted to use 10% of the total time history data. Thus, Design 2 did not become part of the comparison.

TABLE VII
PERCENTAGE DIFFERENCE FOR DIFFERENT TYPES OF BUILDING CONDITION – TOTAL DEFORMATION (MAXIMUM RESULTS)

Building Condition	Total Deformation (mm)	Base Parameter (mm)	% Difference
Fixed	169.54	169.54	0%
Isolated (Design 1)	73.185	169.54	-56.83%
Isolated (Design 2)	72.144	169.54	-57.45%
Isolated (Design 3)	61.825	169.54	-63.53%

The table above shows the percent difference in total deformation for different chosen Building Conditions – Isolation Techniques. The fixed base with 169.54 deformations has a 0 percent difference since it was the base parameter. On the other hand, Design 1 decreased by 56.83 percent deformation. Meanwhile, in Design 2, there was a decrease of 57.45 percent in terms of its deformation. In the Design 3, 63.53 percent of deformation was obtained. This implies that Design 3 decreased by 63.53 percent. Therefore, Design 3, in terms of total deformation, governs.

TABLE VII
PERCENTAGE DIFFERENCE FOR DIFFERENT TYPES OF BUILDING CONDITION – TOTAL ACCELERATION (MAXIMUM RESULTS)

Building Condition	Total Acceleration (m/s^2)	Base Parameter (m/s^2)	% Difference
Fixed	0.035781	0.035781	0%
Isolated (Design 1)	0.01647	0.035781	-53.97%
Isolated (Design 2)	0.00143	0.035781	-96.00%
Isolated (Design 3)	0.010919	0.035781	-69.48%

The table displays the percentage difference in total acceleration for Building Conditions - Isolation Techniques. Fixed Base shows 0% of acceleration percentage difference since it is the base parameter. Design 1 on the other hand, reduced total acceleration by 53.97 percent. A total of 96.00 percent was recorded for Design 2. This means that it has a rapid movement during seismic activity. Design 3 decreased by 69.48 percent. Therefore, the Design 3 Governs in terms of Total Acceleration.

TABLE VIII
PERCENTAGE DIFFERENCE FOR DIFFERENT TYPES OF BUILDING CONDITION – SHEAR STRESS (MAXIMUM RESULTS)

Building Condition	Shear Stress (MPa)	Base Parameter (MPa)	% Difference
Fixed	9.411	9.411	0%
Isolated (Design 1)	14.935	9.411	+58.70%
Isolated (Design 2)	7.4185	9.411	-21.17%
Isolated (Design 3)	17.928	9.411	+90.50%

The table shows the percent difference in Shear Stress for different chosen Building Conditions—isolation Techniques. The fixed base with 9.411 shear stress shows a 0 percent difference since it was the base parameter. Design 1 increased by 58.70 percent in deformation. Meanwhile, Design 2 decreased by 21.17 percent in shear stress. In Design 3, an increase of 90.50 percent in deformation was obtained. This implies that none of the tire-based base isolation techniques governs since Designs 1 and 3 showed increased results.

TABLE IX
PERCENTAGE DIFFERENCE FOR DIFFERENT TYPES OF BUILDING CONDITION – ELASTIC STRAIN (MAXIMUM RESULTS)

Building Condition	Equivalent Elastic Strain (m/m)	Base Parameter (m/m)	% Difference
Fixed	0.007757	0.007757	0%
Isolated (Design 1)	0.006693	0.007757	-13.72%
Isolated (Design 2)	0.005079	0.007757	-34.53%
Isolated (Design 3)	0.002576	0.007757	-66.79%

The table displays the percentage difference in equivalent elastic strain for various Building Conditions. For the Fixed Base, it also shows a 0 percent difference since it was the base parameter. The Design 1 had a 13.72 decrease in elastic strain. On the other hand, 34.53 percent was decreased in Design 2. Lastly, a total of 66.79 percent was obtained in Design 3. Hence, Design 3 governs Equivalent Elastic Strain.

M. ANOVA with Single Factor

In this section, the ANOVA test determined whether there would be a statistically significant difference in the population means of the four groups, the independent variables which were the fixed base, Design 1, Design 2 and Design 3. Further, the evaluation was done to determine whether the treatment levels exhibited significant differences from the observed mean of the dependent variables. These were the four parameters, particularly the total deformation, total acceleration, shear stress, and equivalent elastic strain.

TABLE X
ONE-WAY ANOVA – DIFFERENT CONDITION OF SIX-STOREY BUILDING (TOTAL DEFORMATION)

ONE-WAY ANOVA DIFFERENT CONDITION OF SIX-STOREY BUILDING (Fixed, Design 1, Design 2 and Design 3)					
		df	**F**	**P-value**	**F-Crit**
Maximum	Between Groups	3	55.867	0.00	2.6213
	Within Groups	541			
	Total	544			
Average	Between Groups	3	41.437	0.00	2.6213
	Within Groups	541			
	Total	544			

Upon observing the results, the total deformation in maximum value shows that F is greater than the F-critical, and the P-value of 0.00 was less than the significance value of 0.05. Therefore, the mean was not the same, and the null hypothesis was rejected. Similarly, the total deformation average value shows that F is also more significant than the F-critical, and the P-value of 0.00 is less than the significance value of 0.05. Therefore, the null hypothesis is rejected, and the means were also not the same. Thus, it shows that there is a significant difference in total deformation.

TABLE XI
ONE-WAY ANOVA – DIFFERENT CONDITION OF SIX-STOREY BUILDING (TOTAL ACCELERATION)

ONE-WAY ANOVA DIFFERENT CONDITION OF SIX-STOREY BUILDING (Fixed, Design 1, Design 2 and Design 3)					
		df	**F**	**P-value**	**F-Crit**
Maximum	Between Groups	3	141.452	0.00	2.6213
	Within Groups	541			
	Total	544			
Average	Between Groups	3	134.693	0.00	2.6213
	Within Groups	541			
	Total	544			

Furthermore, there is a significant difference in the total acceleration of the four design groups because both the total acceleration maximum value and average value show that F is greater than the F-critical. Also, the P-value of 0.00 is less than the significance value of 0.05. Therefore, the means are not the same, and the null hypothesis is rejected.

TABLE XII
ONE-WAY ANOVA – DIFFERENT CONDITION OF SIX-STOREY BUILDING (SHEAR STRESS)

ONE-WAY ANOVA DIFFERENT CONDITION OF SIX-STOREY BUILDING (Fixed, Design 1, Design 2 and Design 3)

		df	F	P-value	F-Crit
Maximum	Between Groups	3	5.954	0.00053	2.6213
	Within Groups	541			
	Total	544			
Average	Between Groups	3	0.01202	0.99819	2.6213
	Within Groups	541			
	Total	544			

Meanwhile, the shear stress in the maximum value shows that the F is greater than the F-critical, and the P-value of 0.00 is less than the significance value of 0.05. Consequently, the data from the test rejects the null hypothesis, and the mean did not have the same result. However, the average value of shear stress shows that the F is less than the F-critical, and the P-value of 0.99819 is greater than the significance value of 0.05. Therefore, the data from the test cannot reject the null hypothesis, and the means are the same. Thus, it shows that the shear stress maximum value has a significant difference, while the average value of shear stress does not have a considerable difference.

TABLE XIII
POST HOC TEST – MULTIPLE COMPARISON FOR DIFFERENT CONDITION OF SIX-STORY BUILDING (TOTAL DEFORMATION)

ONE-WAY ANOVA DIFFERENT CONDITION OF SIX-STOREY BUILDING (Fixed, Design 1, Design 2 and Design 3)					
		df	**F**	**P-value**	**F-Crit**
Maximum	Between Groups	3	106.661	0.00	2.6213
	Within Groups	541			
	Total	544			
Average	Between Groups	3	85.438	0.00	2.6213
	Within Groups	541			
	Total	544			

Moreover, there is a statistically significant difference in the accumulated equivalent elastic strain of the four designs because both the maximum value and average value of equivalent elastic strain show that F is greater than the F-critical. Also, the P-value of 0.00 is less than the significance value of 0.05. Therefore, the data from the test rejects the null hypothesis, and the means are not the same. Thus, there is a statistically significant difference in equivalent elastic strain.

In other words, based on the data above, it is concluded that the total deformation, total acceleration and equivalent elastic strain parameters of the four designs differ significantly from one another. As a result, the shear stress does not vary much compared to the total deformation, total acceleration and equivalent elastic strain.

N. POST HOC Test (Tukey HSD Test)

This section determines the differences between the groups using Tukey's Honestly Significant Difference Post Hoc Test (Tukey's HSD). This would establish which factor primarily influences the significance level.

For the researchers to get the significant values of each category, they used the formula; $HSD = q\sqrt{\frac{MS_W}{n_k}}$, to solve for the Q-Critical Value, which is the least amount of variation that means need to have in order to be significantly distinct.

Further, the researchers got the value of q=3.325 in a table called the studentized range, this was utilized to determine the significance of the difference between pairs of the sample means. Thus, the MS_W is the mean square within each category, and the number of participants n=125 in each category. Moreover, the significance level is the probability of incorrectly rejecting the null hypothesis when it is actually true, therefore the researchers used an alpha level of 0.05 (5%) to get a better balance between the samples.

TABLE XIV
POS HOC TEST – MULTIPLE COMPARISON FOR DIFFERENT CONDITION OF SIX-STOREY BUILDING (TOTAL DEFORMATION)

POST HOC TEST MULTIPLE COMPARISON FOR DIFFERENT CONDITION OFSIX-STOREY BUILDING			
GROUPS	**ABSOLUTE MEAN DIFFERENCE**	**Q-CRITICAL VALUE**	**SIGNIFICANT**
Fixed vs Design 1	0.0001178	0.0000440	Yes
Fixed vs Design 3	0.0000871	0.0000440	Yes
Design 1 vs Design 3	0.0000308	0.0000440	No

In terms of total deformation, the results show that the absolute mean difference, which is 0.0001178, is more significant than the solved Q-critical value, which is 0.0000440. Therefore, the Fixed base and Design 1 have a statistically significant difference. Similarly, the Fixed base and Design 3 have a statistically significant difference because the absolute mean difference is 0.0000871, which is greater than 0.0000440, whereas Design 1 and Design 3 have no statistically significant difference. After all, the absolute mean difference is 0.0000308, which is less than 0.0000440. As a result, in terms of total deformation, the fixed base differs significantly from the other two designs, in contrast to Designs 1 and 3, which do not have significant differences.

TABLE XV
POS HOC TEST – MULTIPLE COMPARISON FOR DIFFERENT CONDITION OF SIX-STOREY BUILDING (TOTAL ACCELERATION)

POST HOC TEST MULTIPLE COMPARISON FOR DIFFERENT CONDITION OFSIX-STOREY BUILDING			
GROUPS	**ABSOLUTE MEAN DIFFERENCE**	**Q-CRITICAL VALUE**	**SIGNIFICANT**
Fixed vs Design 1	0.0089662	0.0017691	Yes
Fixed vs Design 3	0.0110628	0.0017691	Yes
Design 1 vs Design 3	0.0020966	0.0017691	Yes

Additionally, there is also a statistically significant difference in total acceleration between the fixed base and Design 1, with an absolute mean difference value of 0.0089662, which is greater than the solved Q-critical value of total acceleration, which is 0.0017691. Comparably, with an absolute mean difference value of 0.0110628, there is a statistically significant difference between fixed base and Design 3. Then, the absolute mean difference between Design 1 and Design 3 is 0.0020966, which is more than the Q-critical value of 0.0017691, indicating that there is a statistically significant difference. In conclusion, the total acceleration of the three (3) Designs are statistically significantly different from one another.

TABLE XVI
POS HOC TEST – MULTIPLE COMPARISON FOR DIFFERENT CONDITION OF SIX-STOREY BUILDING (SHEAR STRESS)

POST HOC TEST MULTIPLE COMPARISON FOR DIFFERENT CONDITION OFSIX-STOREY BUILDING			
GROUPS	**ABSOLUTE MEAN DIFFERENCE**	**Q-CRITICAL VALUE**	**SIGNIFICANT**
Fixed vs Design 1	250.098	832.591	No
Fixed vs Design 3	923.498	832.591	Yes
Design 1 vs Design 3	1173.597	832.591	Yes

Furthermore, the fixed base and Design 1 have an absolute mean difference of 250.098, which is less than the solved Q-critical value of shear stress, which is 832.591. Therefore, there is no statistically significant difference between them. Meanwhile, the other two pairs of groups which are the fixed base and Design 3, and Design 1 and Design 3, have a statistically significant difference, with an absolute mean difference value of 923.498 and 1173.597, respectively, which are greater than the Q-critical value of 832.591.

TABLE XVII
POS HOC TEST – MULTIPLE COMPARISON FOR DIFFERENT CONDITION OF SIX-STOREY BUILDING (ELASTIC STRAIN)

POST HOC TEST MULTIPLE COMPARISON FOR DIFFERENT CONDITION OFSIX-STOREY BUILDING			
GROUPS	**ABSOLUTE MEAN DIFFERENCE**	**Q-CRITICAL VALUE**	**SIGNIFICANT**
Fixed vs Design 1	0.0012396	0.0002942	Yes
Fixed vs Design 3	0.0005149	0.0002942	Yes
Design 1 vs Design 3	0.0007248	0.0002942	Yes

Moreover, in equivalent elastic strain, fixed base and Design 1 have a statistically significant difference with an absolute mean difference value of 0.0012396. In contrast, Fixed base and Design 3 have an absolute mean difference value of 0.0005149, which is greater than the Q-critical value of 0.0002942. Hence, it implies that there is a statistically significant difference. Similarly, Design 1 and Design 3 have an absolute mean difference of 0.0007248, which is greater than the Q-critical value of equivalent elastic strain, which is 0.0002942. Thus, there is also a statistically significant difference between them.

In accordance with the tables above, the Fixed base and Design 3 exhibit statistically significant differences in total deformation, total acceleration, shear stress, and equivalent elastic strain properties.

IV. CONCLUSIONS

The primary objective of this study was to compare and investigate the effectiveness of the three techniques of tire-based base isolation on seismic performance through a simulation using the engineering software ANSYS. In Graphical Representation of the results, Design 2 always had the lowest value of Shear Stress, Total Acceleration and Equivalent Elastic Strain due to the fact that only 10% of the time history data was applied because the sample failed when 100% of the data was used. Therefore, design 3 governs all parameters except shear stress; for percent difference in deformation for different chosen Building Conditions, the design or technique that gives the most optimal result governs. Taking into consideration that the simulation of design 2 failed, design two will not be part of the comparison. The Fixed Base with 169.54 deformations had a 0 percent difference since it is the base parameter. On the other hand, Design 1 decreased by 56.83 percent deformation.

Meanwhile, Design 2's deformation decreased by 57.45 percent. Design 3's deformation was obtained at 63.53 percent. This implies that Design 3 decreased by 63.53 percent. Therefore, Design 3 governs in terms of total deformation.

In Table 3.6 for acceleration, the fixed base shows a 0 percent difference since it is the base parameter. Design 1, on the other hand, reduced total acceleration by 53.97 percent. A total of 96.00 percent was recorded for Design 2. This means that it has little to no movement due to the 10% ground motion applied. Design 3 decreased by 69.48 percent. Therefore, Design 3 governs in terms of total acceleration.

When it comes to the shear stress, the table shows the percentage difference between the different chosen building conditions. The fixed base with 9.411 shear stress shows a 0 percent difference since it is the base parameter. Design 1 increased by 58.70 percent. Meanwhile, in Design 2, there is a decrease of 21.17 percent in terms of its shear stress. In Design 3, an increase of 90.50 percent in deformation was obtained. This implies that in terms of shear stress, none of the tire-base isolation techniques govern it.

Furthermore, when it comes to Equivalent Elastic Strain, the table displays the percentage difference in equivalent elastic strain for various Building Conditions. The Fixed Base has a 0 percent difference since it is the base parameter.

The Design 1 has a 13.72 decrease in equivalent elastic strain. On the other hand, 34.53 percent was decreased in Design 2. Lastly, a total of 66.79 percent was obtained in Design 3. Hence, Design 3 governs Equivalent Elastic Strain.

Lastly, the ANOVA test determined whether there was a statistically significant difference in the population means of the four groups, the independent variables of which were the fixed base, Design 1, Design 2, and Design 3. Upon observing the results, Total Deformation, Total Acceleration and Equivalent Elastic Strain Design 3 govern all. The Post Hoc Test determines which particular group influences the significance level. In accordance with the tables above, the fixed base and Design 3 exhibit statistically significant differences with regard to total deformation, total acceleration, shear stress, and equivalent elastic strain properties. Overall, it was concluded that Design 3: Layer of Rubber Tire Sheet in Between Steel Plates differs significantly and, therefore, is the most optimal tire-based base isolation technique amongst the three chosen.

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