EXPERIMENTAL INVESTIGATIONS TO ASSESS THE PERFORMANCE OF INDIGENOUSLY DESIGNED BASE ISOLATORS USING SHAKE TABLE

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Abstract

Earthquakes are by far the most unpredictable and highly destructive as compared to other natural disasters, releasing large amount of energy in the form of vibrations that damage structures. Base isolation provides earthquake resistance to the structure. Mechanism of base isolators increases the natural period of the overall structure and decreases its acceleration response to seismic motion. The existing research and knowledge based on the physical characteristics of different types of seismic base isolators and the validity of assumptions involved in the design can be strengthened with shake table tests. In this paper, experimentation is carried out using Lead sandwiched with Rubber layer as Base Isolators for a 4-storeyed prefabricated single bay steel frame model. The performance of the base isolators are evaluated using Shake Table Tests and the efficiency of the base isolators is demonstrated. Comparative study is done on the test analysis results of with base isolation and without base isolation. Lead Rubber Isolators are found to reduce the vibrations transmitted to the upper storeys

Keywords: *Earthquake, Base Isolation, Shake Table Tests, Lead Rubber Bearings etc.*

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1. INTRODUCTION

Earthquakes are by far the most unpredictable and highly destructive as compared to other natural disasters. It is the shaking of the earth's surface as a result of sudden release of energy in the earth's lithosphere thus creating seismic waves. Earthquakes that are of tectonic origin have proved to be the most devastating and their area of influence is also quite large, these earthquakes result from a series of earth movements brought about by sudden release of energy during tectonic activities in the earth's crust.

Base isolator is defined as a flexible material which is provided at the basement level to reduce the seismic forces acting on the structure. Base isolation is provided at the basement level because it reduces the ground motion transmitted to the superstructure above, the isolator thus reducing the response of the typical structure and the corresponding loading. Main objective of seismic isolation is to introduce horizontally flexible but vertically stiff components (base isolators) at the base of the building to substantially uncouple the super structure from high frequency earthquake shaking. The basic concept of base isolation system is lengthening the natural period of the fixed base building. Firstly, the isolation system introduces a layer of low lateral stiffness between the structure and the foundation underneath; this isolation layer provides the structure with a natural period much longer than its fixed base natural period.

2. LITERATURE REVIEW

Experimental Investigations on Seismic Responses of Base Isolated Model [1] The model here was a two-bay, three storied soft first-story structure with six columns, brick infills being provided only at the second and third-story levels. Overall height of the structure was 2.6 m. Natural rubber was used as base isolation material. The structure was tested on a uniaxial shaking table applying different synthetic acceleration time histories. Peak ground acceleration (PGA) values are 0.54, 0.83, 0.14 and 0.16 times "g". Peak ground displacement (PGD) values are 4.7, 3.4, 9.7 and 5.7 mm respectively. The narrowband acceleration time histories applied as input excited different rigid body modes of the superstructure such as lateral translation and rocking. The test concludes that the efficiency of the isolation system was more for high frequency earthquakes. Ground motions corresponding to high frequency content between 5 and 10 hertz excited the unsymmetrical rocking modes of the structure due to difference in the vertical stiffness of the isolators

Smart Base Isolation Systems: A newly proposed smart base isolation system was experimentally evaluated for its seismic performance. This system includes Magneto-Rheological elastomers which are fabricated using silicon resin with 30% of 10 micron meter sized iron particles by volume. The MR elastomers were placed between two electro magnets whose input currents when changed adjust the stiffness of the MR elastomers, The MR elastomers were installed in a single story shear building structure, the dynamic characteristics and response of the smart base isolated structure under harmonic loadings were examined and the results show that smart base isolation system reduced the response of the scaled building structure and out performed an equivalent passive type base isolation system**[2]**

Seismic Response Comparison of a Fixed Base building with a Base Isolated building: In this research, an existing hospital building situated at Agartala (seismic zone 5) which is a 7 storey RC beam-column framed structure with brick infill walls and four shear walls of fixed base and isolated base has been compared. The base isolating devices used are lead rubber bearings. Analysis is done by using ETABS version 13. The result observed that with the isolator the structural effects like storey drifts reduced by 39% in the top floor in direction X and 7% in the top floor in direction Y and the story displacements were also reduced. Percentage reduction of base shear was 43% along X reduction and 21% along Y direction. It was also seen that reinforcements required in beams was reduced by 17% and in columns by 25% and in shear walls by 36% therefore bringing about total 20% savings in reinforcements used **[3]**

3. MATERIALS AND METHODOLOGY

3.1 Materials Used

- **Rubber** is a natural or synthetic material whose long coiled high-molecular weight chains have been cross-linked by certain chemical ingredients to form a network. For engineering and industrial applications they are generally compounded with fillers usually carbon black which greatly affect the properties of rubber such as tear and abrasion resistance, other chemicals are also added which protect the rubber from sunlight ozone and oxygen. Rubber is characterized by its ability to accept and recover from extreme deformations. Advantages of rubber include its ease of handling and installation, energy storage capacity and ability to convert some energy to heat when it is deflected. Two types of rubber are used in this experimentation work i.e. soft rubber which is 80 mm thick and hard rubber which is 130 mm thick.

- **Lead** when it is being hot worked, it continually returns to its initial state by the interrelated processes of recovery, recrystallization and grain growth. Lead in the form of 2 mm thick sheets is used in this experimentation work.

- Lead and Rubber when together bonded provides both as elastic component from rubber side and plastic component from lead shearing side.

3.2 Fabrication

Lead sheets and Rubber sheet of different stiffness i.e. Hard Rubber and Soft Rubber are cut to a measurement of 50 mm by 50 mm square with a central hole of 6 mm diameter. The following figures explain the arrangement of Rubber sheets and Lead sheets.

Rubber Sheets of Less Stiffness (Hard Rubber)

Fig -1: Base Isolator made up Hard Rubber

Rubber Sheets of a Higher Stiffness (Soft Rubber)

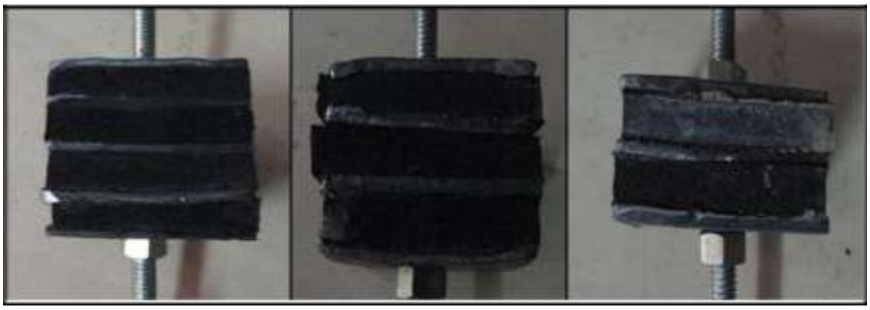

Fig -2: Base Isolator made up Soft Rubber

3.3 Methodology

- Lead Rubber Isolators are firmly mounted on to the base plate of the shake table. Prefabricated 4-storey single bay frame model is then fixed to the Lead Rubber Isolator as shown in the **Error! Reference source not found.**3 below.

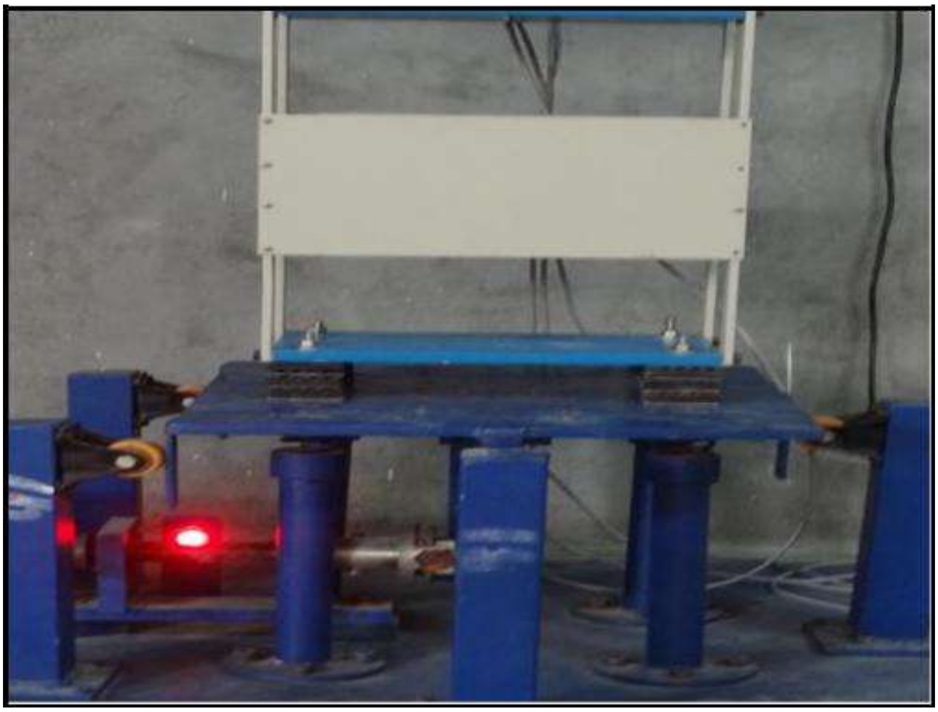

Fig -3: Lead Rubber Isolator fixed to the Shake Table and Model

- Accelerometers named Ch1, Ch2, Ch3 and Ch4 are fixed at respective storey 1, 2, 3 and 4, they are further connected to respective Channels Ch1, Ch2, Ch3 and Ch4 on the connecting end of the IEICOS Signal Conditioning Amplifier which in turn is connected to the IEICOS Data Acquisition System [DAS]. IEICOS DAS has a built in USB port to connect to the computer. IEICOS DAS Software for Shake Table Experiment has been installed in the computer.
- At each storey level the Accelerometers are fixed along X direction and tested and then fixed along Y direction and again tested. The following Figure represents all the equipment's along with the Lead Rubber Isolator and the prefabricated 4-storey building frame needed to carry out the experiment.

Fig -4: Complete set up needed to carry out the Experiment

- Once the entire set up shown in **Error! Reference source not found.**4 is ready, Free Vibration test is carried on the structure by giving a small tap on the model which is read by the sensors and the result is displayed on the computer screen in the form of frequency vs acceleration graph.
- Once the Free Vibration test is done the DC Motor is switched on and the readings are taken at 250 RPM 500 RPM 750 RPM and 1000 RPM along both X and Y directions of the accelerometer placing for the prefabricated model with Isolation and Without Isolation, and the same is done for Z direction by shifting to the vertical Shake Table and carrying out the tests for 100 RPM 200 RPM 300 RPM 400 RPM and 500 RPM.
- The results in the form of excel sheets are obtained from the computer which is further studied and reported.

4. RESULTS AND DISCUSSIONS

4.1 Free Vibration Test Results

Natural frequency of the prefabricated 4-storey single bay steel structure was found by installing sensors at each storey. The sensors have sensitivity of 4mvolt/g therefore a small tap on the structure is sufficient to create the vibration in the structure as to measure the natural frequency of the whole structure.

Table -1: Free Vibration Test Results

Sl.no.	storey	Acceleration (m/s^2)	Frequency(Hz)
1	Ground	6.93 x 10-5 m/s2	3 Hz
2	First	1.03x10-3 m/s2.	1 Hz
3	Second	1.08 x 10^{-3} m/s^2.	1 Hz
4	Third	3.08 x 10^{-3} m/s^2.	1 Hz
5	Fourth	6.51 x 10^{-4} m/s^2.	1 Hz
Sl.no.	storey	Acceleration (m/s^2)	Frequency(Hz)

4.2 Shake Table Test Results

4.2.1 At 250 RPM along X and Y direction

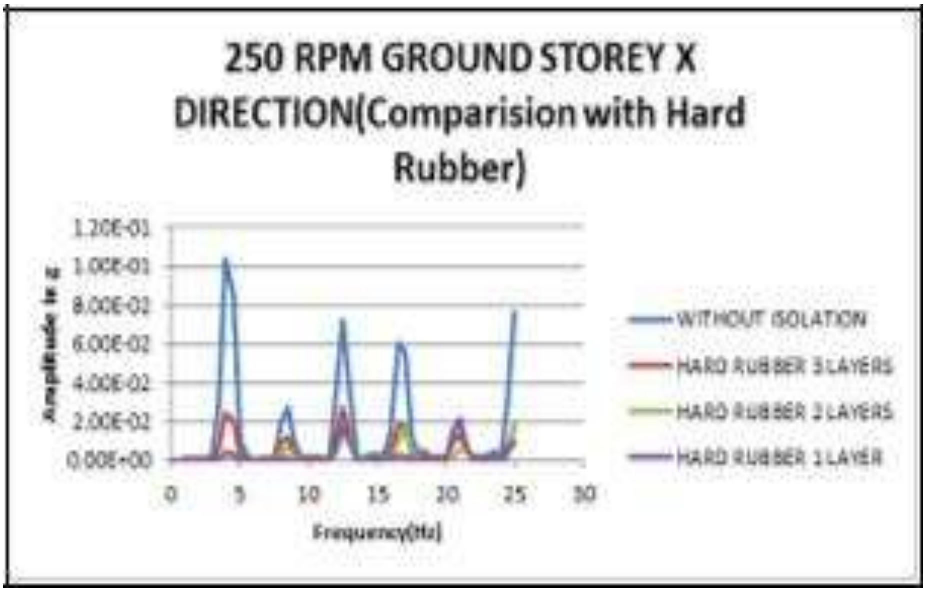

Fig- 5: Comparison between Hard Rubber Isolators and Without Isolation

Fishows the comparison between the amount of vibrations absorbed by the base isolator having 3 layers of hard rubber, 2 layers of hard rubber and 1 layer of hard rubber against no isolation. From this graph it is observed that base isolator having hard rubber 1 layer is more efficient in absorbing the vibrations as compared to the other two types.

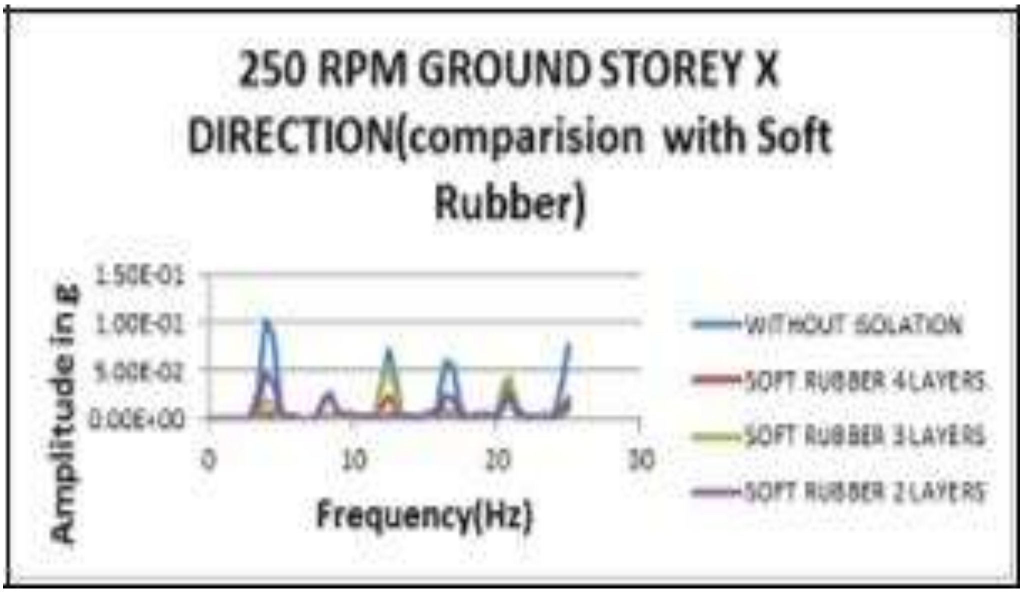

Fig-6: Comparison between Soft Rubber Isolators and Without Isolation

Fig6 shows the comparison between the amount of vibrations absorbed by the base isolator having 4 layers of soft rubber, 3 layers of soft rubber and 2 layer of soft rubber against no isolation. From this graph it is observed that base isolator having soft rubber 4 layer is more efficient in absorbing the vibrations as compared to the other two types. Similarly at 1000 RPM Isolator having 1 layer of Hard Rubber and 4 layers of Soft Rubber has been proved to be efficient.

From the Fi5 and Fig6 it is observed that Base Isolator made up of 1 layer of Hard Rubber and 4 layers of Soft Rubber is best at absorbing vibrations when compared to the other types of base isolators used in this experiment. Tests have been carried out at 250, 500, 750 and 1000 RPM along X and Y direction, and at 100, 200, 300 400 and 500 RPM along Z direction. Results of the tests at 250 RPM, 1000 RPM along X and Y direction are presented in this paper.

Ground Storey along X Direction

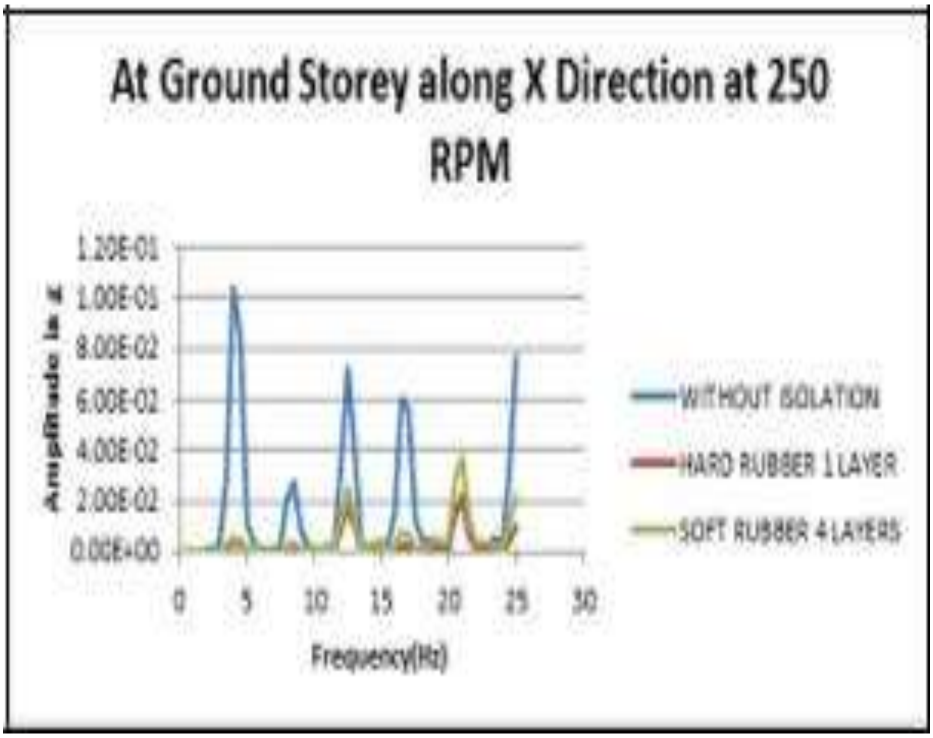

Fig-7: Vibrations absorbed at ground storey along X direction at 250 RPM

Table 2: Vibrations reduced by Hard and Soft Rubber at 250RPM along X direction at Ground Storey

Frequency(Hz)	Percentage reduction by Hard Rubber of 1 layer	Percentage reduction by soft rubber of 4 layers
4	96.6%	94.41%
8.5	97.65%	90.20%
12.5	75.83%	65.41%
16.5	95.92%	88.18%
25	86.81%	71.27%

Ground Storey along Y Direction

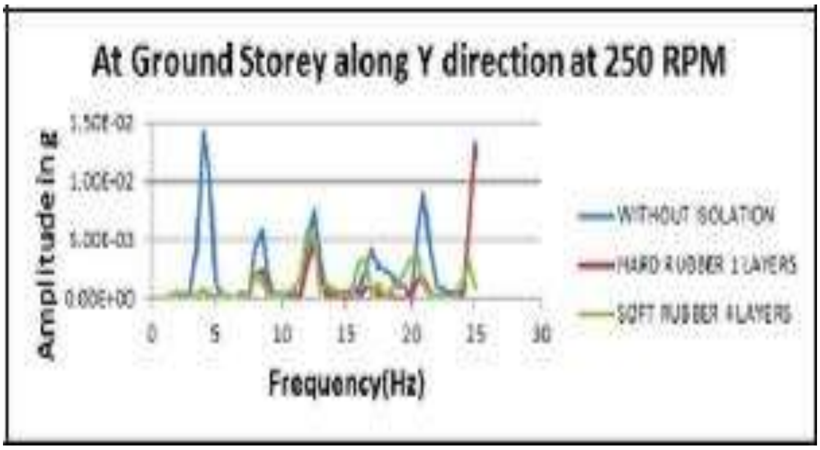

Fig-8: Vibrations absorbed at ground storey along Y direction at 250 RPM

Table 3: Vibrations reduced by Hard and Soft Rubber at 250RPM along Y direction at Ground Storey

Frequency(Hz)	Percentage reduction by hard rubber of 1 layer	Percentage reduction by soft rubber of 4 layers
4	95.28%	94.3%
8.5	57.58%	75.51%
12.5	33.81%	30.76%
17	75.42%	92.24%
21	80.22%	86.62%
25	5.30%	93.56%

4.2.2 At 1000 RPM along X and Y direction

Ground Storey along X Direction

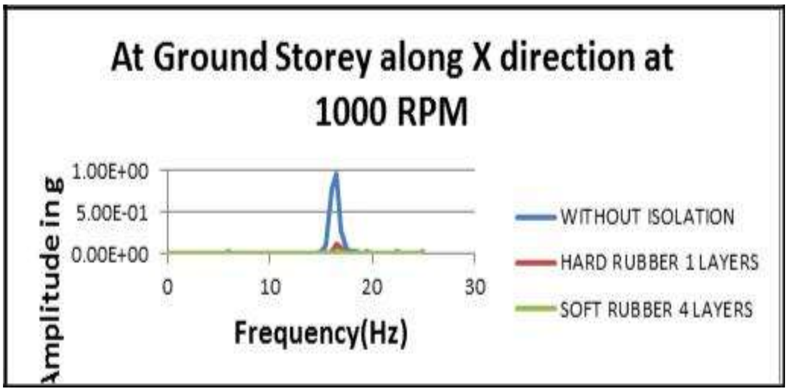

Fig-9: Vibrations absorbed at ground storey along X direction at 1000 RPM

Table 3: Vibrations reduced by Hard and Soft Rubber at 1000 RPM along X direction at Ground Storey

Frequency(Hz)	Percentage reduction by Hard Rubber of 1 layer	Percentage reduction by Soft Rubber of 4 layers
16.5	88.5%	96.64%

Ground Storey along Y Direction

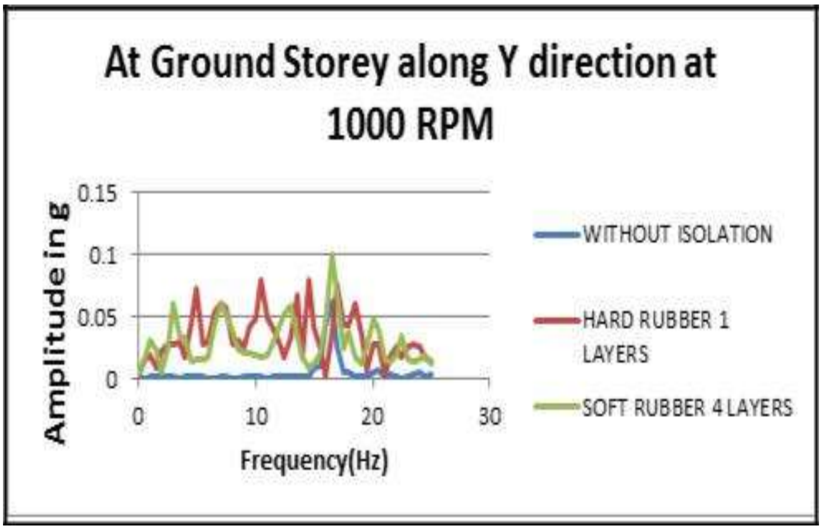

Fig-10: Vibrations absorbed at ground storey along Y direction at 1000 RPM

5. CONCLUSION

- From the Free Vibration graphs it is observed that the Natural Frequency of the Prefabricated 4-Storey Single Bay Steel Structure is 3Hz at Ground Storey and 1Hz at 1st, 2nd , 3rd and 4th Storey.
- Comparison between base isolators made up of Hard Rubber is made and it is found that the Base Isolator made up of Hard Rubber of 1 layer was found to be more efficient in absorbing vibrations than the Base Isolators made up of Hard Rubber 2 layers and 3 layers.
- Comparison between base isolators made up of Soft Rubber is made and it is found that the Base Isolator made up of Soft Rubber of 4 layers was found to be more efficient in absorbing vibrations than the Base Isolators made up of Soft Rubber 3 layers and 2 layers.

- Base Isolator made up of Hard rubber 1 layer and Soft Rubber 4 layers are found to be most efficient in absorbing vibrations in this experiment.
- Test results show that at 250 RPM the Base Isolators made up of Hard Rubber 1 layer and Soft Rubber 4 layers were efficient in absorbing vibrations along both X and Y directions at Ground, 1st, 2nd, 3rd and 4th storeys.
- Test results show that at 1000 RPM the Base Isolators were efficient in absorbing vibrations at Ground storey along X direction and 2nd 3rd and 4th storey along both X and Y direction but failed to absorb vibrations at Ground storey along Y direction and at 1st storey along both X and Y directions.
- Tests were performed on the vertical shake table considering it as the Z direction. At 100RPM the Base Isolators were efficient in absorbing the vibrations at 1st, 2nd and 3rd storey but failed to absorb vibrations at Ground and 4th storey.
- Tests were performed on the vertical shake table considering it as the Z direction. At 500RPM the Base Isolators were efficient in absorbing the vibrations at Ground, 1st, 3rd and 4th storey but failed to absorb vibrations at 2nd storey

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REFERENCES

[1] Anand S.Arya, "Concepts and Techniques for Seismic Base Isolation of Structures," in *Earthquake Engineering, Tenth World Conference* , Balkerna,Rotterdam, 1994.

[2] Seung-Hyun Eem; Hyung-Jo Jung; Jeong-Hoi Koo, "Application of M R Elastomers for Improving Seismic Protection of Base Isolated Structures," *IEEE,* vol. 47, no. 10, pp. 0018-9464, 2011.

[3] Meena Noorzai;M.N.Bajad;Neha Dodal, "Study Response of Fixed Base and Isolation Base," *International Journal of Innovative Research in Science, Engineering and Technology,* vol. 4, no. 5, pp. 2374-6710, 2015.

[4] Syed Ahmed Kabeer K I; Sanjeev Kumar K.S, "Comparison of Two Similar Buildings with and without Base Isolation," *international journal of advance research,ideas and innovations in technology.*, vol. 1, no. 1, 2014.

[5] Takehiko Asai; Chia-Ming Chang; B.F.Spencer Jr, "Real Time Hybrid Simulation of a Smart Base-Isolated Building," *Journal of Engineering Mechanics,* vol. 141, no. 3, pp. 0733-9399, 2014.

[6] Hnini Hnini Hlaing; Dr. Kyaw Moe Aung, "Comparative Study on Seismic Resistant Design using Base Isolation Systems," *International Journal of Scientific Engineering and Technology Research,* vol. 03, no. 09, pp. 1597-1603, 2014.