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THE INVESTIGATION BASE ISOLATOR IN CONTROLLING THE RESPONSE OF THE STRUCTURES DURING EARTHQUAKES

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ABSTRACT

Base isolation systems are among the most successful and widely applied methods of mitigating structural vibration and damage during seismic events. These systems have been installed in numerous full-scale structures all around. There are three principal types of base isolators: Lead Rubber Bearing (LRB), High Damping Rubber Bearing (HDRB), and Friction Pendulum System (FPS). It is necessary to extensively examine the response of different LRB isolators—by combining them with re-centering and damping properties for isolated steel frame buildings experiencing several NF ground motions. The present research uses comparative-descriptive methodology and application in terms of objectives. The data needed for the study were collected using library references and through reviewing related studies conducted in the past in the same field.

Results of the current comparative investigation indicated significant reductions in the storey drift, shear, and acceleration and increment in the storey displacement. According to the findings of the current study, base isolators provide flexibility to massive structures against earthquakes. These structures are situated on rigid soils. Moreover, base isolation was found to be the most effective in controlling the response of the structures during earthquakes. Finally, shear, storey drift, and storey displacement reduce due to the use of base isolators as compared to the fixed-base structure.

Key words: *base isolator, seismic response, structure, earthquake, story displacement*

INTRODUCTION

Base isolation systems are among the most successful and widely applied methods of mitigating structural vibration and damage during seismic events. They have been installed in numerous full-scale structures all around [1,2,3,4]. However, the near-fault, high-velocity, and long-period seismic pulses recorded during the Northridge and Kobe earthquakes have proved to the engineers and researchers that the ground motion due to such earthquakes can be difficult to accommodate. For example, a base isolated structure in one region of Los Angeles that readily survived the 1994 Northridge earthquake may well have been destroyed if it was located elsewhere in the region [5]. A base isolation system that can adapt to and protect against seismic excitation of differing characteristics may help mitigate these problems. Design codes for seismic isolation have quite conservative requirements. This can lead to large isolators, costly flexible utility connections, and expensive loss of space for the seismic gap. To alleviate these effects, isolators have been augmented with supplemental damping devices [6]. However, the effect is to decrease the base drift at the expense of increasing floor acceleration and structure inter-storey drifts. Furthermore, when designed for Maximum Capable Earthquake (MCE), extremely low-probability events and little isolation may be realized in more probable moderate earthquakes [7]. Several active base control systems have been proposed and studied [8,9,10,11,12].

The aim was to supplement passive base-isolation with active control devices in order to limit base drift. Several small-scale experiments have been performed to verify the effectiveness found in the simulation studies [13]. Base Isolation is one of the passive energy dissipation techniques for earthquake resistant designs of a structure. It is useful in controlling energy, which gets transmitted from the foundation or ground to the upper stories. The main use of the isolation system is to decrease the displacements, base reactions, and member forces in the structure [14]. As a case study, rubber isolation structures have the highest response reduction factor as compared to fixed frame [15].

TYPES OF BASE ISOLATORS

Base isolation technique decouples the structure from the ground, preventing the superstructure from absorbing input energy. It is effective in low to medium rise buildings on hard soil. Seismic isolation systems contribute to safety by withstanding lateral forces. Moreover, a base isolation system decouples the superstructure from the seismic ground motions, extending the fundamental period of excitation. Base isolation is employed where safety is a major concern. There are three principle types of base isolators: Lead Rubber Bearing (LRB), High Damping Rubber Bearing (HDRB), and Friction Pendulum System (FPS). As a case study, FPS isolator has got greater increase in time period than LRB isolator [15].

LEAD RUBBER BEARING (LRB)

The most common base isolation devices used over many years by engineers are Lead Rubber Bearing (LRB) isolators. These isolators combine isolation function and energy dissipation in a single compact unit [14,15]. Such LRB isolator devices provide vertical load support, horizontal flexibility, supplemental damping, and centering force to the structure to resist earthquake attacks. Furthermore, they require minimal cost for installation and maintenance as compared to other passive vibration control devices [16,17]. The LRB isolator typically consists of laminated rubber layers with a lead core plug at its center, as illustrated in Figure 1 [18,19,20,].

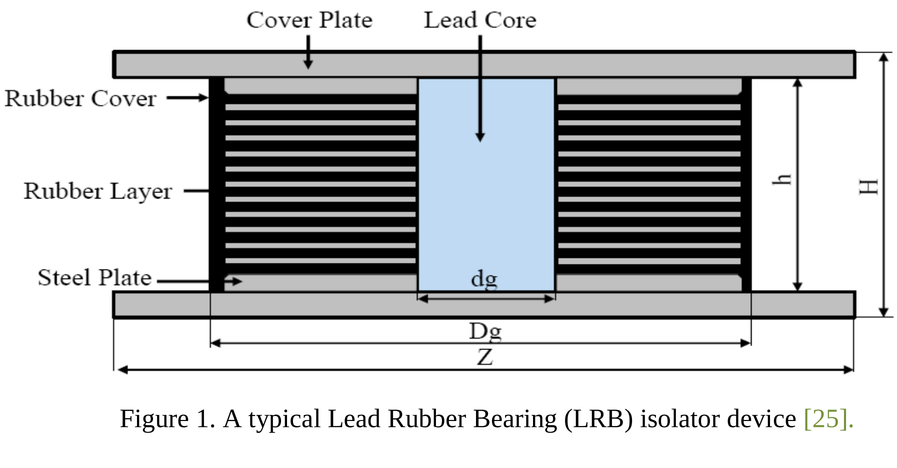

Figure 1. A typical Lead Rubber Bearing (LRB) isolator device [25].

The low-damping elastomers, constructed with elastomeric rubber bearings, generally behave in an elastic manner toward external responses. Thus, they can instantly provide isolation capacity, additional flexibility, and elastic re-centering force to the LRB isolator device [21]. On the other hand, the lead core, which yields at a relatively low shear stress, responds with perfectly elasto-plastic loops.

Therefore, it offers not only sufficient energy dissipation but also supplemental damping component. The inner reinforcing stacked-up steel plates constrain the laminated rubber layers from lateral expansion. The Cover Plate Lead Core provides high vertical stiffness, resisting gravity loads. The typical LRB isolator has considerable maximum shear strains, ranging between 125% and 200%. This is because the reinforcing steel plates have little effect on the shear stiffness. Therefore, installation of the LRB isolator devices may be necessary for the frame buildings in order to mitigate structural damage [22].

A considerable amount of practical research on the use of this elastomeric LRB isolator has been conducted for several years. The early stage of research development has mainly focused on LRB responses, estimated through experimental observations and numerical analyses—including LRB system design [23]. The stiffness models were developed to predict the force-displacement response of the LRB isolator device. On the other hand, recent researches have been trending toward the application of LRB isolation systems in building structures [21,24].

LRB isolators, with hardening behavior, were developed for low to mid-rise buildings, located in the moderate seismicity area. Moreover, the behavior of the base-isolated building was accurately predicted by nonlinear dynamic analyses, performed with relatively long-period ground motions. Most recently, some researchers have started evaluating seismic performance and capacity for the base-isolated multi-storey building structures, subjected to several NF ground motions [22,23,24].

The NF ground motions produce strong acceleration pulses with undesirable effects on the response of the superstructures, causing severe failure and instability in the superstructure. Accordingly, the LRB base isolators are required for building structures located on the NF sites. They reduce such ground accelerations, which are transmitted into the superstructure, very effectively. The seismic performance for the base-isolated building under the NF ground motion generates sufficient interest for many engineers and scientists. However, until now, there was a lack of proper research regarding practical implementation of LRB isolator devices in actual frame buildings. Therefore, it is necessary to extensively examine the response of different LRB isolators, combining them with the re-centering and damping properties, on isolated steel frame buildings, experiencing several NF ground motions [25].

Basic Functions of LRB's

- Load supporting function: Rubber reinforced with steel plates provides stable support for structures. Multilayer construction provides better vertical rigidity for supporting a building than single layer rubber pads.
- Horizontal elasticity function: With the help of LRB, earthquake motion is converted to low speed motion. As horizontal stiffness of multilayer rubber bearing is low, strong earthquake vibration is lessened and the oscillation period of the building is increased.
- Restoration function: Horizontal elasticity of LRB helps the building return to its original position. Elasticity in LRB mainly comes from restoring force of the rubber layers. After an earthquake, this restoring force helps the building return to the original position.
- Damping Function: Provides required amount of damping that is necessary [26].

HIGH DAMPING RUBBER BEARING (HDRB)

HDRB is a type of elastomeric bearing. This type of bearing consists of thin layers of high damping rubber and steel plates built in alternate layers. The vertical stiffness of the bearing is several hundred times the horizontal stiffness. This is due to the presence of internal steel plates. Horizontal stiffness of the bearing is controlled by the low shear modulus of elastomeric, while the steel plates provide high vertical stiffness as well as prevent the rubber from bulging. High vertical stiffness of the bearing has no effect on the horizontal stiffness. Rubber, reinforced with steel plates, provides stable support for structures. Multilayer construction provides better vertical rigidity for supporting a building than single layer rubber pads. With the help of HDRB, earthquake vibration is converted to low speed motion. As horizontal stiffness of the multi- layer rubber bearing is low, strong earthquake vibration is lessened and the oscillation period of the building is increased. Horizontal elasticity of HDRB helps return the building to its original position. In an HDRB, elasticity mainly comes from the restoring force of the rubber layers. After an earthquake, this restoring force helps the building get back to the original position [27]. Figure 2 shows a typical HDRB isolator device.

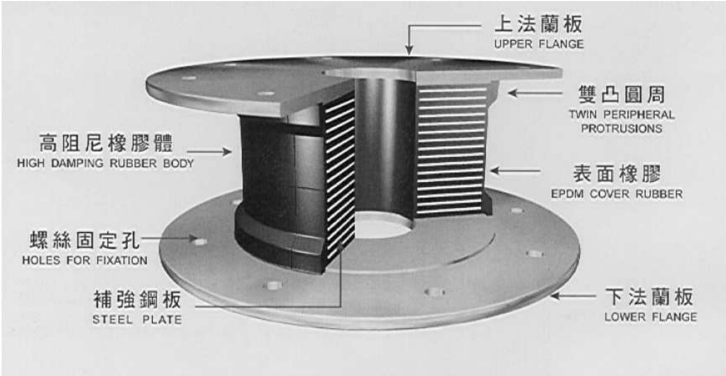

Figure 2. Typical High Damping Rubber Bearing (HDRB) isolator device

FRICTION PENDULUM SYSTEM (FPS)

The FPS is a sliding type isolation system and consists of a spherical stainless-steel surface and an articulated slider, covered by Teflon-based composite material. It works on the principle of simple pendulum. The friction pendulum bearings are seismic isolators that are installed between a structure and its foundation to protect the supported structure from ground shaking caused by an earthquake. The cross-sectional view of FPS is shown in Figure 3 [28].

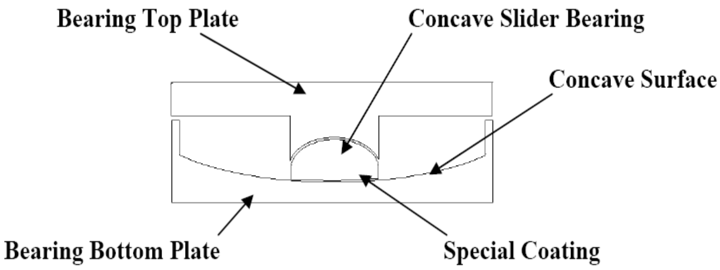

Figure 3. Cross section Friction Pendulum System (FPS) isolator device [29]

The spring-like bearings that have seen widespread application include the LRB and the HDRB. The sliding type bearings, on the other hand, are impractical due to the lack of restoring capability. To overcome this drawback, the FPS (originated from the sliding type bearings) is developed by introducing a spherical sliding interface. This restores the stiffness, while the friction between the sliding interfaces helps in dissipating the energy.

As a result, the FPS is functionally equivalent to LRB and HDRB in lengthening structures fundamental period. Moreover, FPS has additional advantages such as a period-invariance, torsion resistance, temperature-insensitivity, and durability. Although the rubber bearings have been extensively adopted for seismic isolation, the FPS has recently found increasing applications. The friction pendulum bearings provide strength and stability that exceed those of rubber bearings. Its properties are not affected by again or temperature. The bearing’s low profile, high strength, and high vertical stiffness reduce installation costs. These bearings offer versatile properties, which can satisfy the diverse requirements of buildings, bridges, and industrial facilities [29,30,31].

CONCEPT OF FRICTION PENDULUM BEARINGS

Friction pendulum bearings work on the same principle as that of a simple pendulum. When activated during an earthquake, the articulated slider moves along the concave surface, causing the structure to move in small simple harmonic motions. This is illustrated in Figure 4. Similar to a simple pendulum, the bearings increase the structures' natural period by causing the building to slide along the concave inner surface of the bearing. The bearings filter out the imparting earthquake forces through the frictional interface. This frictional interface also generates a dynamic friction force that acts as a damping system in the event of an earthquake. This lateral displacement greatly reduces the forces transmitted to the structure, even during earthquakes as strong as of magnitude eight. This type of system also possesses a re-centering capability. This allows the structure to center itself, in case any displacement occurs during a seismic event due to the concave surface of the bearings and gravity [32].

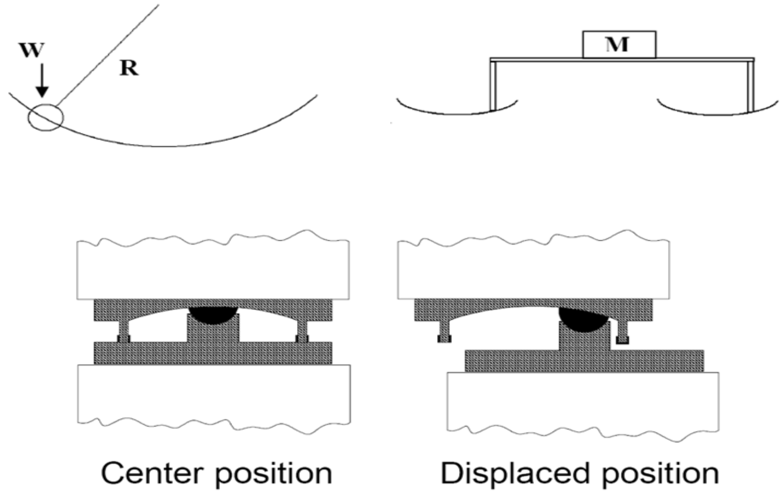

Figure 4. Concept of sliding pendulum motion

EFFECT-BASED ISOLATORS IN DESIGN PARAMETERS IN DIFFERENCE STRUCTURES

S.M. Dhawade presented a comparative study on seismic performance of the base-isolated and fixed-based RC frame structures. The high density rubber isolator was used as an isolation device. The study presented by the author was conducted on (G+14) structures, using the ETABS software. A linear static analysis was carried out on the given structures. Presented below is a comparative study between fixed-base and base-isolated structures. The result showed reduction in the storey drift, shear, and acceleration and increment in the storey displacement. The storey displacement in this case study is presented in Table 1 [27].

Table1: Comparative results for storey displacement

Story No	Lateral Load To Stories (KN)			
	In X- Direction		In Y- Direction	
	(Fixed Base)	(Base Isolated)	(Fixed Base)	(Base Isolated)
14	59.84	0.37	95.74	0.37
13	58.70	0.37	91.84	0.37
12	55.93	0.37	87.15	0.37
11	47.48	0.34	73.89	0.34
10	39.84	0.31	61.92	0.31
09	32.52	0.28	49.95	0.28
08	25.85	0.25	40.07	0.25
07	20.16	0.22	31.22	0.22
06	14.96	0.19	23.67	0.19
05	10.73	0.16	16.65	0.16
04	7.32	0.13	11.45	0.13
03	4.39	0.10	6.75	0.10
02	2.28	0.07	3.64	0.07
01	1.14	0.04	1.56	0.04
Base	0.00	0.00	0.00	0.00

N. R. Chandak presented the work reelected to Effect of Base Isolation on the Response of Reinforced Concrete Building. The six storey building is analyzed with rubber isolating device and by providing friction pendulum isolation device at its base. The analysis was done by using the response spectrum analysis. Results obtained from the presented work shows that there is reduction in base shear, storey drift, storey shear, and torque and increment in the storey displacement [33].

Santosh H.P, et al. presented the work on seismic analysis of low- to medium-rise buildings for base isolation. The lead rubber isolator was used as an isolating device, and the analysis was done by using STAAD Pro software. The six-storey building was analyzed both by considering it as fixed-base structure and then by considering it as a base-isolated structure, by means of lead rubber bearings. The analytical results obtained showed the reduction in storey acceleration and storey shear in the case of base-isolated structure as compared to non-isolated structure [34].

Torunbalci N. et al. presented the analytical study on mid-storey building by considering various seismic isolation techniques. For a case study, a six-storey building was analyzed by using three dimensional non-linear time history analysis. The analysis was done on the basis of various seismic isolation and energy dissipating alternatives. Alternatives included rubber bearings, friction pendulum bearings, additional isolated storey, and viscous dampers [35]. Further, A.R. Akhare et al. presented the work on the (G+12)-storey hospital building and issued it as a test model. Non-linear time history analysis was carried out for both fixed-base and base-isolated structures. The result obtained, as shown in Figure 5, displayed the reduction in base shear in both directions and a reduction in the displacement and drifts for the base-isolated structure. Reduction in the drifts in Y direction is presented in Figure 6 for this case study [25].

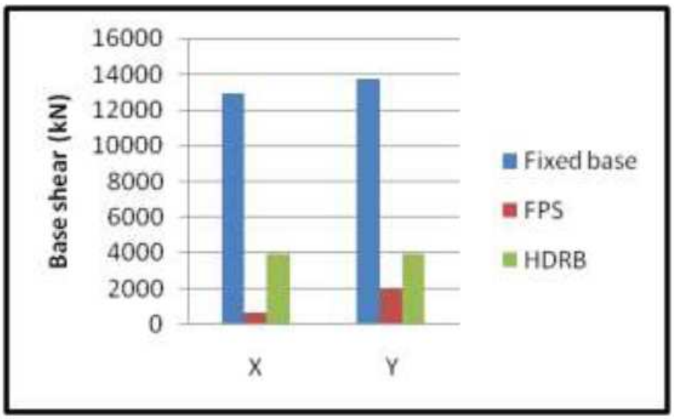

Figure 5. Base shear force in X and Y directions with different base isolators

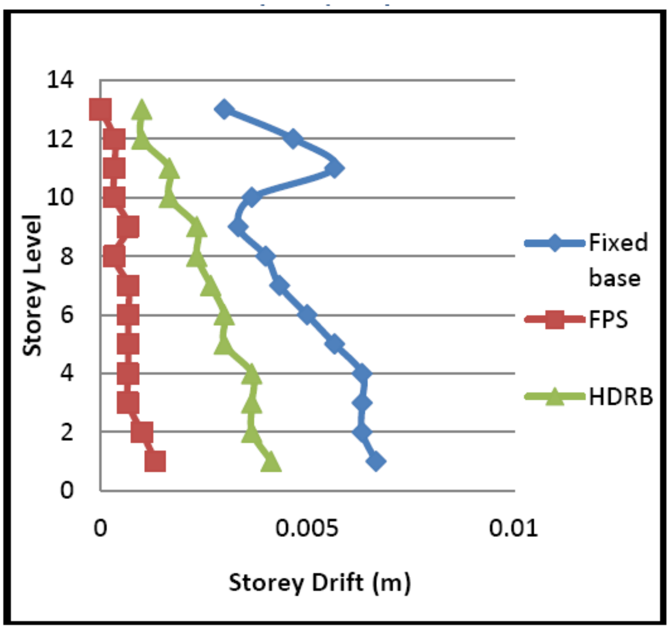

Figure 6. Storey drift in Y direction with different base isolators

S.A Kabeer K I. et al. presented the study analysis to check the adequacy of the base isolation against earthquake damage when compared to the conventional earthquake resistant design. A building was analyzed using the equivalent lateral force method and response spectrum analysis as fixed-base and isolated-base with lead rubber bearing. The analysis represents a case study for reinforced concrete to show the ultimate capacity of the selected bearing system. It also makes a comparison between isolated-base and fixed-base buildings.

Results show that the presence of the lead rubber bearing reduces displacement, moment, and shear generated for the same mode significantly. Therefore, the reinforcement required is also lesser when compared to the traditional fixed-based structure. Difference in quantity of the reinforcement provided for the two cases of fixed-base and isolated-base buildings is shown in Table 2. It is shown that the lead rubber bearing can bring about 20% savings in reinforcement [36].

Table 2: Comparison of quantity of reinforcements in fixed-base and isolated-base buildings

Reinforcement m^3		Fixed Base	Isolated Base	Percentage reduction
1	Beams	8.93	7.45	16.57
2	Columns	2.84	2.13	25.00
3	Shear wall	1.63	1.03	36.35
	Sum	13.40	10.61	20.76

CONCLUSIONS

Base isolators provide flexibility to massive structures situated on rigid soils against earthquakes.

Base isolation is most effective in controlling the structures during earthquakes.

Base shear, storey drift, and storey displacement decrease due to the use of base isolators, as compared to the fixed-base structure.

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REFERENCES

[1] Kelly, J.M. (1981). Aseismic Base Isolation: Its History and Prospects. Proc. 1st World Congress on Joints and Bearings, ACI-SP-70, 1: 549-586.
[2] Buckle, I.G. and Mayes, R.L. (1990). Seismic Isolation History, Application and Performance — A World View. Earthquake Spectra, 6: 161-201.
[3] Soong, T.T. and Constantinou M.C. (1994). Passive and Active Structural Vibration Control in Civil Engineering. Springer-Verlag, Wien and New York.
[4] Skinner, R.I., Robinson, W.H. and McVerry, G.H. (1993). An Introduction to Seismic Isolation, John Wiley & Sons Ltd, Chichester, England.
[5] Makris, N. (1997). Rigidity-Plasticity-Viscosity: Can Electrorheological Dampers Protect Base-Isolated Structures from Near-Source Earthquakes. Earthquake Engrg. and Struct. Dyn., 26: 571-591.
[6] Asher, J.W., Young, R.P. Ewing, R.D. (1996). Seismic Isolation Design of the San Bernardino County Medical Center Replacement Project. J. of Struct. Des. of Tall Bldgs., 5: 265-279.
[7] Elsesser. E. (1997). Forell/Elsesser Engineers, Inc., Private communication. International Conference of Building Officials (1997), Uniform Building Code, Earthquake Regulations for Seismic Isolated Structures, Appendix Chapter 16, Whittier, CA.
[8] Reinhorn. A.M., Soong. T.T., Wen, C.Y. (1987). Base-Isolated Structures with Active Control. Proc. ASME PVP Conf., San Diego, CA, PVP-127: 413-420.
[9] Kelly, J.M., Leitmann, G., Soldatos, A.G. (1987). Robust Contorl of Base-Isolated Structures under Earthquake Excitation. J. of Optimization Theory and Applications, 53: 159-180.
[10] Yoshida, K., Kang, S., Kim, T. (1994). LQG Control and H¥ Control of Vibration Isolation for Multi-Degree-of-Freedom Systems. Proc. 1st World Conf. on Struct. Control, Los Angeles, CA, TP4: 43-52.
[11] Schmitendorf, W.E., Jabbari, F., Yang, J.N. (1994). Robust Control Techniques for Buildings Under Earthquake Excitation. Earthquake Engineering and Structural Dynamics, 23: 539-552.
[12] Yang, J.N., Wu, J.C., Reinhorn, A.M., Riley M. (1996). Control of Sliding-Isolated Buildings Using Sliding-Mode Control. Journal of Structural Engineering, ASCE, 122: 179-186.

[13] Reinhorn, A.M., Riley, M. (1994). Control of Bridge Vibrations with Hybrid Devices. Proc. 1st World Conf. on Struct. Control, Los Angeles, CA, TA2: 50-59.

[14] Ahmadi, S.L., Tadjbakhsh, I.G. (1989). A comparative study of performances of various base isolation systems, Part 1: Shear beam structures. Earthq. Eng. Struct. Dyn., 18: 11–32.

[15] Chen, C., Yeh, K., Liu F. (2009). Adaptive fuzzy sliding model control for seismically excited bridges with lead rubber bearing isolation. Int. J. Uncertain. Fuzz. 17: 705–727.

[16] Lee-Glauser, G.J., Ahmadi, G., Horta, L.G. (1997), Integrated passive/active vibration absorber for multistory buildings. ASCE J. Struct. Eng. 123: 499–504.

[17] Aparna, V., Ashutosh, G., Baikunth, N. (2017) Base Isolation Systems: A Review. International Journal of Engineering Science Invention (IJESI), 6: 43-46.

[18] Beeraiah, B., Chandra Sekhar, G. (2017), earthquake response of reinforced concrete multistory building with base isolation, International Journal of Research Sciences and Advanced Engineering, 2:149–154.

[19] Chandran, S., Vijayan M. (2017). Analysis of Earthquake Response on RC Structure with and without Base Isolation in Different Plan Shapes, International Research Journal of Engineering and Technology (IRJET), 4: 1634-1641.

[20] Ahmadi, S.L., Tadjbakhsh, I.G. (1989). A comparative study of performances of various base isolation systems, Part 1: Shear beam structures. Earthq. Eng. Struct. Dyn. 18: 11–32.

[21] Chen, C., Yeh, K., Liu F. (2009), Adaptive fuzzy sliding model control for seismically excited bridges with lead rubber bearing isolation. Int. J. Uncertain. Fuzz. 17: 705–727.

[22] Lee-Glauser, G.J., Ahmadi, G., Horta, L.G. (1997), Integrated passive/active vibration absorber for multistory buildings. ASCE J. Struct. Eng., 123: 499–504.

[23] Su, L., Ahmadi, G., Tadjbakhsh, I.G. (1989). Comparative study of base isolation systems. ASCE J. Eng. Mech., 115: 1976–1992.

[24] Robinson, W.H. (1982). Lead-rubber hysteretic bearings suitable for protecting structures during earthquakes. Earthq. Eng. Struct. Dyn., 10: 593–604.

[25] Hu, J.W. (2015), Response of Seismically Isolated Steel Frame Buildings with Sustainable Lead-Rubber Bearing (LRB) Isolator Devices Subjected to Near-Fault (NF) Ground Motions", Sustainability 7: 111-137.

[26] Soong, T.T., Spencer, B.F. (2002), Supplemental energy dissipation: State-of-the-art and state-of-the-practice. Eng. Struct. 24: 243–259.

[27] Providakis, C.P. (2008), Effect of LRB isolators and supplemental viscous dampers on seismic isolated buildings under near-fault excitations. Eng. Struct., 30: 1187–1198.

[28] Hall, J.F., Heaton, T.H., Halling, M.W., Wald D.J. (1995), Near-source ground motion and its effects onflexible buildings. Earthq. Spectra, 11: 569–605.

[30] Rao, P.B., Jangid, R.S. (2001). Performance of sliding systems under near-fault motions. Nucl. Eng. Des. 203: 259–272.

[31] Shen, J., Tsai M., Chang, K., Lee, C.G. (2004). Performance of a seismically isolated bridge under near-fault earthquake ground motions. ASCE J. Struct. Eng., 130: 861–868.

[32] Ashish, R., Tejas, A., Wankhade, R. (2014). Seismic Performance of RC Structure Using Different Base Isolator", International Journal of Engineering Sciences and Research Technology, 3(5): 724-729.

[33] Khannavar, S., Kolhar, M.H., Algur, A. (2017), Seismic Analysis of RC Structures Using Base Isolation Technique, International Journal of Emerging Research in Management &Technology, 6: 166- 175.

[34] Dhawade, S. M. (2014). Comparative Study for Seismic Performance of Base Isolated & Fixed Based RC Frame Structure, International Journal of Civil Engineering Research, 5: 183-190.

[35] Wang, Y.P. (2014). Fundamental of Seismic Base Isolations, In proceeding of "International Training Programs for Seismic Design of Building Structures", National Chiao-Tung University, Hsinchu, Taiwan. Pp. 139-148.

[36] Kravchuk, N., Colquhoun, R., Porbaha, A. (2008), Development of a Friction Pendulum Bearing Base Isolation System for Earthquake Engineering Education", Proceedings of the 2008 American Society for Engineering Education Pacific Southwest Annual Conference, American Society for Engineering Education.