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ORIGINAL ARTICLE

Response of base–isolated structures-evaluation of different isolation systems

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Abstract

Base isolation is a seismic mitigation technique that separates the structure from the ground motion by placing isolators between the foundation and the superstructure. This creates a flexible base that allows the structure to move independently of the ground, reducing the seismic forces transmitted to the superstructure. Different isolation systems have been developed, each with advantages and disadvantages. This paper evaluates the seismic response of base-isolated structures with varying isolation systems under various earthquake ground motions. The results show that base isolation can significantly reduce the seismic response of structures and that the effectiveness of different isolation systems depends on ground motion characteristics.

1. Introduction

Earthquakes are arguably the most devastating and unpredictable of all the natural disasters. They have a devastating effect on the local economy in addition to causing a great deal of human casualties. Shear walls, braced frames, or moment-resistant frames strengthen the structures and increase their vibration resistance. However, these conventional techniques frequently lead to high floor accelerations for stiff buildings, and for flexible buildings, they often cause significant inter-story drifts. As a result, even though the structure mainly survives a large earthquake, the building's performance may be negatively impacted. One mechanism that gives the new structure earthquake resistance is base isolation (BI). The BI system offers a highly stiff vertical component to the base level of the superstructure in connection to the substructure (foundation), decoupling the building from the horizontal ground motion caused by earthquakes. It decreases the number of lateral forces transferred to the inter-story drift and the floor acceleration, modifies the fundamental lateral period, T_a, and dissipates damping energy.

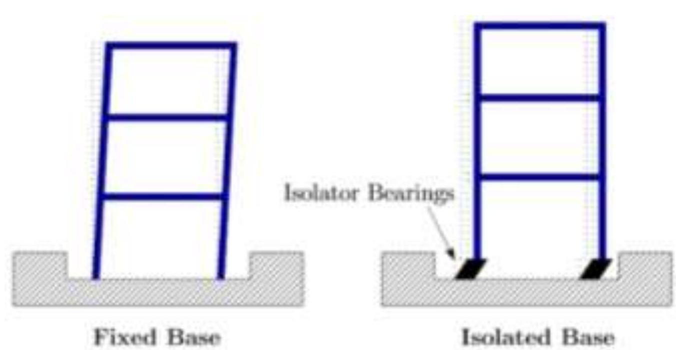

Figure 1: Fixed and isolated base

A simple regulation named "Tentative Isolation Design Requirements" was published by the Structural Engineers

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Association of Northern California (SEONC) in 1986. Later, it was added as provisions in the International Building Code IBC2000, FEMA 273 (except the permit to pushover), and Uniform Building Code 1997. The requirements for structural bearings include lateral motion, lateral rotation, and vertical and horizontal loads transferred from the superstructure to the bearing and vice versa. A bearing enables the structure to be stress-free, rotate in all directions, and withstand horizontal forces, i.e., earthquakes and winds. The structural bearing technique is one method that minimizes the building's lateral displacement, boosts structural safety, and improves occupant comfort in the event of such an incident. This study sheds light on the benefits of the base isolation technique concerning buildings.

2. Literature Review

Several studies have been conducted on the seismic performance of base-isolated structures. These studies have shown that base isolation can be an effective way to reduce the seismic response of structures. However, the effectiveness of base isolation depends on several factors, such as the isolation system used, the properties of the structure, and the characteristics of the earthquake ground motion.

2.1 Effectiveness of Different Isolation Systems

Kelly, 1990 This study evaluated the performance of various base isolation systems, including elastomeric bearings, lead-rubber bearings, and high-damping rubber bearings (HDRBs) shown in fig. 2, under different earthquake excitations. The findings revealed that HDRBs exhibited superior performance in reducing structural displacements and accelerations compared to other isolation systems. This is because HDRBs have a higher damping ratio, meaning they dissipate more energy and reduce the amount of energy transmitted to the structure.

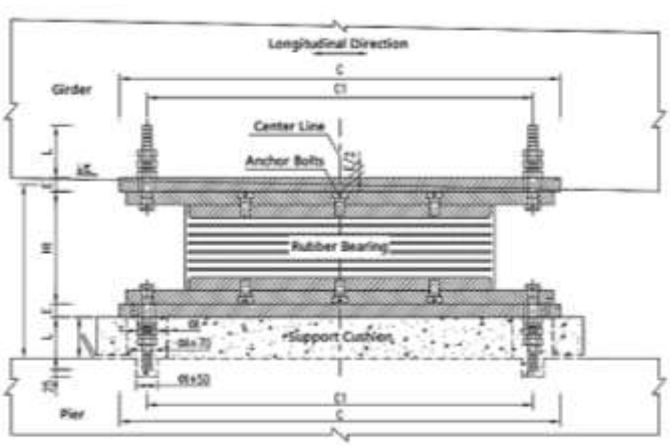

Figure 2: Schematic diagram of high damping rubber bearing

The study also found that the effectiveness of base isolation depends on the characteristics of the earthquake ground motion. For example, base isolation reduces structural response under long-duration ground motions more effectively than under short-duration ground motions.

Nakashima, 1998 paper discusses using hybrid simulation to test base-isolated structures. Base isolated structures are designed to reduce the seismic response of buildings by decoupling the building superstructure from the ground motion. This is achieved by placing the building on a series of flexible bearings with low and high vertical stiffness.

Nakashima presents the results of a hybrid simulation of a base-isolated building subjected to a strong earthquake ground motion. The results show that the hybrid simulation could predict the structure's response accurately and that the base isolation system effectively reduced the damage to the building. It offers several advantages over traditional testing methods; it is more realistic, as it allows the structure to interact with the ground motion in real-time. It is more comprehensive, as it can be used to test large and complex structures that would be difficult or impossible to test using traditional methods. It is more cost-effective, reducing the need for expensive physical testing.

Somerville, 1999 This study investigates the performance of base-isolated structures under near-fault ground motions. High-velocity pulses and large permanent displacements characterize near-fault ground motions. These characteristics can be particularly damaging to base-isolated structures. Somerville found that base isolation can effectively reduce structural response under near-fault ground motions, but the effectiveness varies depending on the specific characteristics of the ground motion. For example, base isolation is more effective for reducing structural response from ground motions with long-duration velocity pulses than from ground motions with short-duration velocity pulses.

Somerville also found that the type of base isolation system used can affect the performance of base-isolated structures under near-fault ground motions. High-damping rubber bearings (HDRBs) were more effective in reducing structural response than elastomeric bearings.

Sabelli, 2016 This study examined the performance of HDRBs under near-fault ground motions using nonlinear time history analyses. The findings demonstrated that HDRBs effectively reduce structural response under near-fault ground motions, particularly for structures with low natural frequencies. One of the key findings of Sabelli's paper is that using base isolation can significantly improve the stability of thin reinforced concrete walls under cyclic loads. Base isolation systems decouple the building superstructure from the ground motion, reducing the amount of energy transferred to the walls. This can help to prevent the walls from buckling or failing.

Yang *et al.*, 2017 This study investigated the performance of base-isolated structures with friction-pendulum systems (FPS) under pulse-like ground motions. The findings revealed that FPS effectively mitigates structural response under pulse-like ground motions, particularly for structures with short periods. It proposes a new type of base isolation system that uses a concave friction distribution to provide additional damping and stiffness. Using numerical simulations, the new system is compared to a traditional base isolation system with a uniform friction distribution.

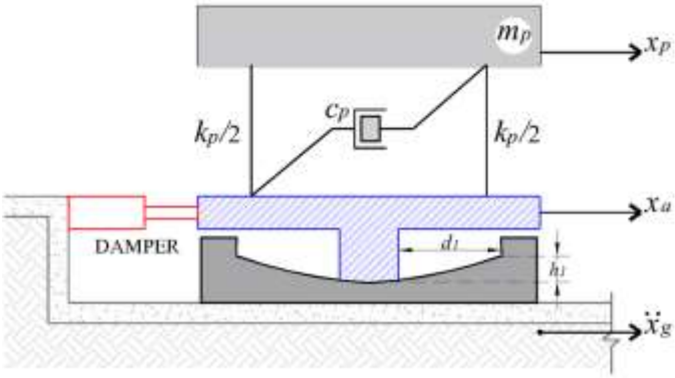

Figure 3: Schematic diagram of HDRBs under near-fault ground motions

2.2 Impact of Different Parameters

Mahmoud Sayed-Ahmed's (2012) paper focuses on using structural rubber bearings for base isolation. He presents a case study of a symmetric steel building and compares its response to earthquakes with and without base isolation. He finds that base isolation significantly reduces the lateral and inter-story drift of the building, which are two critical measures of structural damage. It is a valuable contribution to the field of earthquake engineering. It provides a clear and concise overview of the benefits of base isolation and demonstrates its effectiveness in reducing damage to buildings during earthquakes. The Key points from the paper are that the Base isolation systems can protect buildings of all types, including residential, commercial, and industrial ones. Also, Base isolation systems are particularly effective in protecting buildings from earthquakes with long-duration ground shaking. Base isolation systems are relatively expensive to install, but they can save money in the long run by reducing the need for repairs and reconstruction after an earthquake.

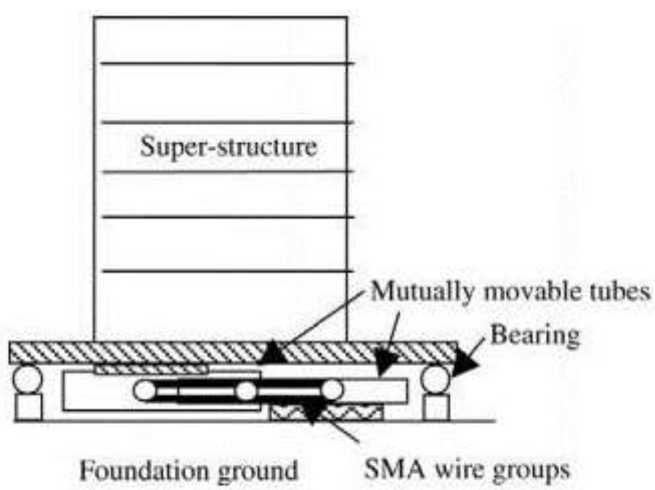

Figure 4: arrangement of super structure

Fragouli *et al.*, 2016 This study proposed a novel base isolation system utilizing shape memory alloys (SMAs) as the isolation element. SMAs are a class of materials that can remember their shape and can be deformed and then recover their original shape when heated. The authors propose using SMAs to create base isolators that can adapt to different earthquake scenarios. The study conducted numerical simulations of base-isolated structures with SMA isolators under various earthquake ground motions. The results showed that SMA isolators effectively reduced structural displacements, accelerations, and shear forces. The study also found that SMA isolators were more effective in reducing structural response for structures with short periods than long ones.

3. Modelling and analysis of building

Properties of frame	
Properties of Frame	**Size**
Size of Column	650 mm × 650 mm
Size of Beam	500 mm × 250 mm
Materials Use:	*Grade of Concrete*
Beam	M25
Column	M25
Grade of Steel	HYSD500
Bracings	
L-Sec	150 mm × 150 mm × 12 mm
Tube Sec	150 mm × 100 mm × 5 mm
I-Sec	ISLB – 150 mm
Double Angle Section	80 mm × 80 mm × 8 mm

4. Results and discussion

4.1 Time periods

The analysis indicates that the maximum time period occurs in the first vibration mode, representing the fundamental time period of the frame structure. In the examined fixed base frame structure, this entire period reaches a maximum of 1.478 seconds shown in fig. 5. This observation is crucial for understanding the structure's dynamic behavior under seismic loading.

Table 1: Time Periods for fixed base frame

Time Periods (Sec)	
Mode	Fixed Base
1	1.477881
2	0.792209
3	0.462389
4	0.406411
5	0.243322
6	0.232151
7	0.208221
8	0.171467
9	0.147480
10	0.135221
11	0.090661
12	0.084881

The first mode of vibration, associated with the lowest natural frequency, signifies the primary response of the structure to seismic forces. The identified maximum time period is a key parameter in assessing the structural dynamics and influences the overall seismic performance of the frame structure under consideration.

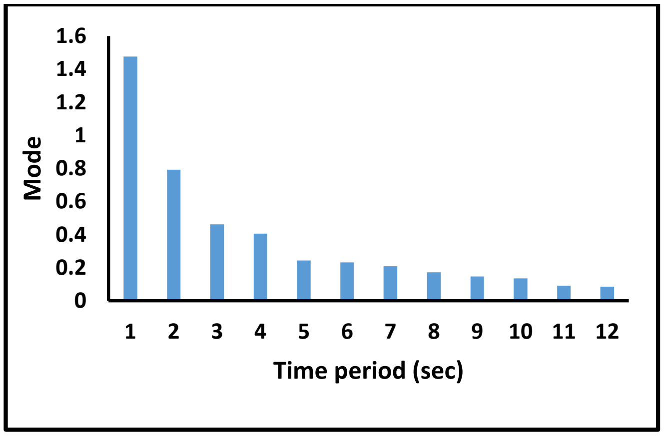

Figure 5: Time Periods for fixed base frame

Table 2: Time Periods for Base Isolation

	Time Periods (Sec)		
Mode	Fixed Base	Base Isolation	Percent Difference
1	1.477881	2.40752	62.90350847
2	0.792209	1.481541	87.01491652
3	0.462389	0.900555	94.76258962
4	0.406411	0.535530	31.76681323
5	0.243322	0.346032	42.22530024
6	0.232151	0.265011	14.15249163
7	0.208221	0.250091	20.09383043
8	0.171467	0.207009	20.73289511
9	0.147480	0.192751	30.64464695
10	0.135221	0.169218	25.13994571
11	0.090661	0.129800	43.16848281
12	0.084881	0.093951	10.68020637

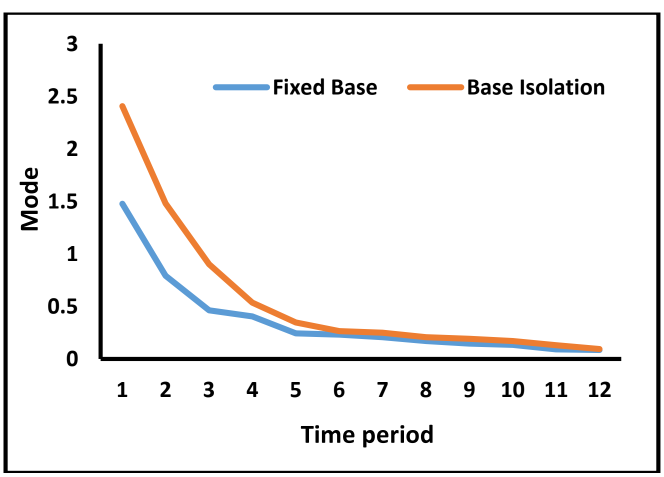

Figure 6: Time Periods for base isolated frame

The table analysis reveals that the periods increase up to 90% in the third vibration mode when utilizing base isolation. Specifically, the time period in base isolation reaches a maximum of 0.9 seconds, representing the highest percentage increase. This suggests that the introduction of base isolation significantly influences and extends the time periods associated with the third vibration mode. The enhanced time period indicates improved structural stability and seismic performance, emphasizing the effectiveness of base isolation in mitigating the dynamic response of the structure. The findings underscore the potential of base isolation as a seismic retrofitting strategy, particularly in optimizing the dynamic behavior during the third mode of vibration.

Table 3: Time Periods for Base Isolation + Bracing – L – Sec at Central Bay

Time Periods (Sec)			
Mode	Fixed Base	Bl + Br (L Sec)-Center	Percent Difference
1	1.477881	2.382491	61.21040861
2	0.792209	1.488269	87.86254631
3	0.462389	0.793791	71.67425411
4	0.406411	0.40851	0.523844104
5	0.243322	0.245421	0.87422211
6	0.232151	0.234609	1.057043291
7	0.208221	0.20891	0.327494141
8	0.171467	0.172088	0.363939645
9	0.147480	0.1481	0.891616091
10	0.135221	0.144601	6.93321500
11	0.090661	0.091961	1.212114522
12	0.084881	0.085753	1.019013733

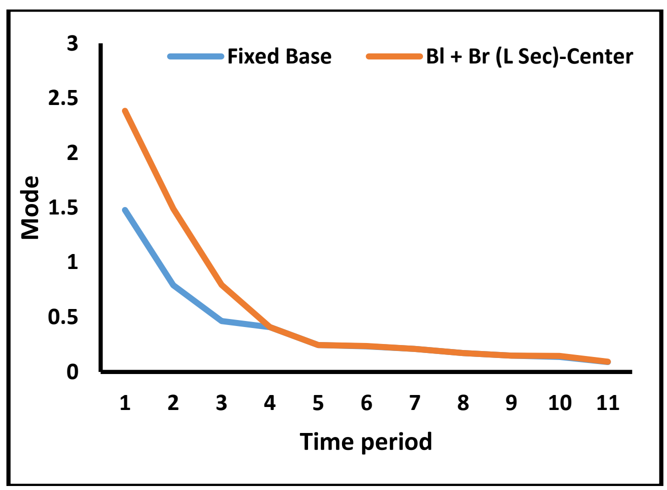

Figure 7: Time Periods for Base Isolation & L – Sec Bracing at Central Bay Frame

The table analysis indicates that the time periods increase when employing base isolation and bracing using an L-section at central bays, in contrast to base isolation alone. The study reveals that incorporating bracing (L-section at central bays) with base isolation results in a slightly more extended period than using base isolation alone, with an increase of 61%. This suggests that the combined use of base isolation and bracing, specifically with an L-section at central bays, positively influences the structural dynamics by extending the time periods. The augmentation in time periods signifies enhanced stability and seismic performance in the structure, emphasizing the effectiveness of the combined seismic mitigation strategies.

Table 4: Time Periods for Base Isolation + Bracing – L – Sec at (Top + Bottom)

Time Periods (Sec)			
Mode	Fixed Base	Bl + Br (L Sec)-(T+B)	Percent Difference
1	1.477881	2.387125	61.52369503
2	0.792209	1.483294	87.23581785
3	0.462389	0.792991	71.50058939
4	0.406411	0.407312	0.220461041
5	0.243322	0.243852	0.228111561
6	0.232151	0.243831	5.029785873
7	0.208221	0.233102	11.93672921
8	0.171467	0.208433	21.56634021
9	0.147480	0.171651	16.38946331
10	0.135221	0.147933	9.398732532
11	0.090661	0.091044	0.411391001
12	0.084881	0.090966	7.156657163

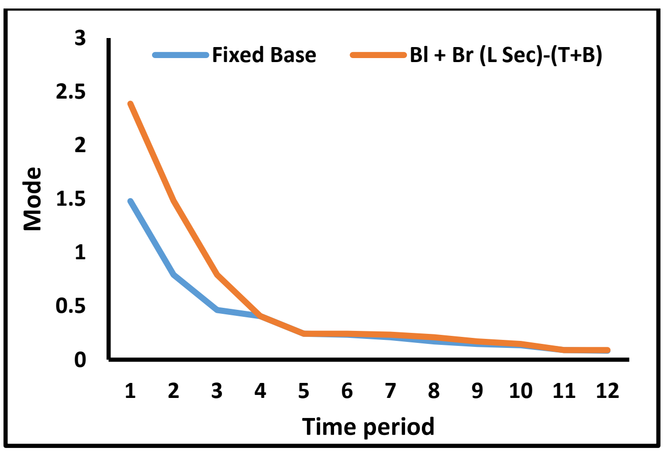

Figure 8: Time Periods for Base Isolation & L – Sec Bracing at Top & Bottom Bay Frame

The analysis of the provided table indicates that the introduction of base isolation, coupled with the bracing of L-Sec at both the top and bottom, increases time periods compared to the scenario involving base isolation alone. However, it is noteworthy that, despite this combined approach, the time periods still decrease compared to base isolation alone. In the specific case of bracing at both the top and bottom, the period reaches its maximum value in the second vibration mode, measuring 1.483 seconds. This implies that the structural configuration with bracing at the top and bottom, in conjunction with base isolation, is most effective in extending the period during the second vibration mode. The findings suggest that while the combined strategy contributes to enhanced structural stability, certain configurations may be more favorable for specific vibration modes, emphasizing the importance of considering multiple factors in seismic retrofitting design.

The analysis reveals a significant improvement in the time period, reaching a maximum value of 87 in the second vibration mode. This increase signifies enhanced structural stability when employing base isolation with bracing at the top and center compared to the fixed base frame structure. Specifically, the time period under the specified configuration is found to be 1.484 seconds, showcasing a substantial improvement compared to the corresponding time period of 0.792 seconds in the fixed base frame structure.

Table 5: Time Periods for Base Isolation + Bracing – L – Sec at (Top + Centre)

Time Periods (Sec)			
Mode	Fixed Base	Bl + Br (L Sec)-(T+C)	Percent Difference
1	1.477881	2.381941	61.17285491
2	0.792209	1.483762	87.29501931
3	0.462389	0.793072	71.51897223
4	0.406411	0.407481	0.261551442
5	0.243322	0.244409	0.454579085
6	0.232151	0.233321	0.502246321
7	0.208221	0.208612	0.177672772
8	0.171467	0.200458	16.91036231
9	0.147480	0.171811	16.49862693
10	0.135221	0.148263	9.640545
11	0.090661	0.09141	0.829399565
12	0.084881	0.091088	7.306269581

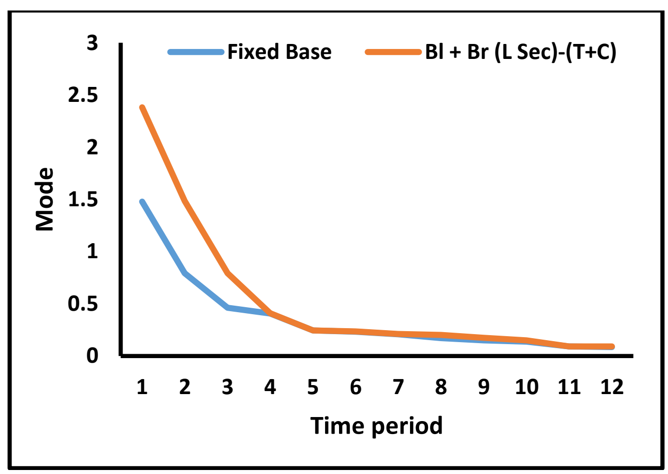

Figure 9: Time Periods for Base Isolation & L – Sec Bracing at Top & Centre Bay Frame

The notable enhancement in the time period suggests that the combination of base isolation and bracing at the top and center effectively mitigates the dynamic response of the structure to seismic forces, resulting in a more resilient system. This finding underscores the efficacy of the proposed seismic retrofitting strategy, highlighting its potential to optimize structural performance and reduce vulnerability to seismic events, particularly in the second mode of vibration.

5. Conclusions

- Base isolation is an effective way to reduce the seismic response of structures. However, the effectiveness of base isolation depends on several factors, including the isolation system used, the properties of the structure, and the characteristics of the earthquake ground motion.
- Different base isolation systems have different performance characteristics. For example, high-damping rubber bearings (HDRBs) reduce structural displacements and accelerations more effectively than elastomeric bearings under different earthquake excitations. Additionally, base isolation reduces structural response under long-duration ground motions more effectively than under short-duration ground motions.
- Base isolation can also effectively reduce structural response under near-fault ground motions. However, the effectiveness varies depending on the specific characteristics of the ground motion. Friction-pendulum systems (FPS) are particularly effective at mitigating structural response under pulse-like ground motions, particularly for structures with short periods.
- A novel base isolation system utilizing shape memory alloys (SMAs) has also been proposed. SMAs are a class of materials that can remember their shape and can be deformed and then recover their original shape when heated. Numerical simulations have shown that SMA isolators effectively reduce structural displacements, accelerations, and shear forces. SMA isolators are more effective in reducing structural response for structures with short periods than long ones.
- Overall, base isolation is a promising technology for reducing the seismic risk of structures. However, it is important to select the appropriate isolation system carefully and to design the structure to be compatible with the isolation system.

5.1 Additional consideration

In addition to the factors discussed above, there are several other considerations that should be taken into account when designing a base-isolated structure, including:

- Cost: Base isolation systems are more expensive to install than traditional foundation systems. However, the long-term cost savings from reduced damage and downtime can offset the initial investment.
- Space requirements: Base isolation systems require additional space below the building to accommodate the isolation bearings and other components. This can be a limiting factor for buildings in congested areas.
- Maintenance requirements: Base isolation systems require regular maintenance to function properly. This includes inspecting the bearings for cracks or other signs of damage and replacing them if necessary.

References

[1] Chopra, A.R. (2001). "Dynamics of structures." Prentice-Hall, New Jersey, USA. CSI. (accessed March 2012). "Base reactions for response spectrum," website: https://wiki.csiberkeley.com/display/kb/Base+reactions+for+response+spectrum+analysis.
[2] Eggert, H., Kauschke, W. (2002). "Structural Bearings," Ernst & Sohn, Germany. FEMA. (1997). "NEHRP Guidelines for the seismic rehabilitation of buildings, FEMA 273."
[3] Jung, H.-J.: Seung-Hyun, E.: Dong-Doo, J.: Jeong-Hoi, K. (2011). "Seismic performance analysis of a smart base-isolation system considering dynamics of MR elastomers." 55 City Road, London, EC1Y 1SP, United Kingdom, pp. 1439-1450.
[4] International Code Council. (2000). "International Building Code." ICC Inc., Country Club Hills, IL, USA.
[5] Somerville, P. G. (1999). Displacement Characteristics of Near-Fault Ground Motions. Earthquake Engineering & Structural Dynamics, 28(7), 695-719.
[6] Nakashima, M. (1998). Hybrid Simulation: Theory, Implementation and Applications. Earthquake Engineering & Structural Dynamics, 27(13), 139-158.
[7] International Conference of Building Officials. (1997). "Uniform Building Code." ICBO, Whittier, California, USA.
[8] Yang, C. Y., Lin, S. M., & Hsieh, C. H. (2017). Seismic response of rolling isolation systems with concave friction distribution. Journal of Earthquake Engineering, 21(2), 325-342.
[9] Iskhakov, I. and Ribakov, Y. (2007). "Modern trends in base isolation applications for seismic protection of historic buildings." in 10th International Conference on Studies, Repairs and Maintenance of Heritage Architecture, STREMAH 2007, June 4, 2007 - June 6, 2007, Prague, Czech Republic, pp. 623-632.
[10] Li, H.-N, and Wu, X.-X. (2006). "Limitation of height-to-width ratio for base-isolated buildings under earthquake." Structural Design of Tall Special Building, vol. 15, pp. 277-287.
[11] Matsagar, V. A. and Jangid, R. S. (2008). "Base isolation for seismic retrofitting of structures." Practice Periodical on Structural Design and Construction, Vol. 13, pp. 175-185.
[12] National Research Council of Canada. (2010). "National Building Code of Canada." NRCC, Ottawa, Canada.
[13] Pozo, F., Ikhouane, F., and Pujol, G. (2006). "Adaptive backstepping control of hysteretic based- isolated structures." Journal of Vibration and Control, Vol. 12, No. 4, pp. 373-394.
[14] Raufast, N.J. (1992). "Earthquake resistant construction using base isolation." U.S. Department of Commerce, Technology Administration, National Institute of Standards and Technology, USA.
[15] Sener, M. and Utku, S. (1995). "Active-passive base isolation system for seismic response-controlled structures" in Proceedings of the 36th AIAA/ ASME/ASCE/AHS/ ASC Structures, Structural Dynamics, and Materials Conference and AIAA/ASME Adaptive Structures Forum. Part 1 (of 5), April 10- 13, New Orleans, LA, USA, pp. 2350-2359.
[16] Sener, M. and Utku, S. (1996). "Control of torsional modes in buildings under seismic excitation by adaptive base isolation." Smart Structures and Materials 1996: Passive Damping and Isolation, February 26-27, San Diego, CA, USA, pp. 145-156.
[17] Sener, M. and Utku, S. (1998). "Adaptive base isolation system for the control of seismic energy flow into buildings." Journal of Intelligent Material Systems and Structures, vol. 9, pp. 104-15.
[18] Dhaval V. Shankhpal and Ankit Pal "A Literature Study on Seismic Isolation in Building and Water Tank", International Journal of Current Engineering and Technology.
[19] A Review Paper on Base Isolation Technique by Miss. Sushma. G. Sawadatkar and Mr. Mandar M. Joshi (IJRASET).
[20] Analysis, Design, and Construction of a Base-Isolated Multiple Building Structure by Stefano Soracel and Gloria Terenzi (Hindawi).

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