CHAPTER 6 CONCLUSION AND FUTURE SCOPE

6.1 General Introduction

Recent advancements in seismic base isolation have garnered significant attention in structural engineering due to its potential to diminish acceleration response, provide structural flexibility, and enhance seismic capacity. Isolators, such as LRB, HDRB and sliding isolation systems, represent sophisticated approaches to managing seismic energy dissipation. These past literatures included in the present thesis offers an in-depth understanding of these systems and their impact on structural performance.

Past reviews highlight the effectiveness of LRB in providing rigidity and damping, while HDRB offer enhanced energy dissipation through increased damping characteristics. Sliding isolation systems, on the other hand, introduce flexibility and minimize transmitted forces but require careful attention to frictional properties. Insights from previous research have informed the experimental and numerical approaches undertaken in this study, deepening the understanding of base isolation systems and their applications. Additionally, the literature review also identified gaps in research and paved way for further exploration. These findings highlight the evolving significance of seismic base isolation and guide future advancements in the field, contributing to more robust structural designs and improved performance during seismic events.

This thesis investigates the behavior of High Damping Rubber Bearings (HDRB), Lead Rubber Bearings (LRB), and sliding isolation systems under various seismic events through numerical simulations and experimental tests. Using advanced software like ABAQUS, SAP2000, and SeismoMatch, along with the PEER NGA West ground motion database, the study thoroughly analyzes these systems' seismic responses.

Numerical simulations revealed that HDRB, LRB, and sliding isolators significantly improve seismic performance by reducing acceleration and enhancing structural flexibility. ABAQUS allowed for detailed modeling, including linear and non-linear springs such as conical springs, to assess their roles in sliding isolation systems. These simulations demonstrated that base isolation effectively mitigates seismic forces on structures.

The experimental study involved quarter-scaled tests of moment-resisting frames with fixed and sliding bases, using a shaking table with Pulse Labshop software. Results from these controlled tests validated the numerical findings, shows that sliding isolation systems, combined with springs, reduce seismic damage more effectively than conventional fixed-base structures.

These findings provide valuable insights for researchers and practitioners, highlighting the advantages of sliding isolators with spring combinations as base isolation in enhancing seismic resilience. The research recommends further exploration through larger-scale tests, field validation, and the development of new isolation technologies to optimize seismic design.

6.2 Conclusion

The conclusion of this research provides significant insights into the intricacies and practical applications of seismic base isolation systems. Below are the key findings derived from the current thesis analysis, numerical simulation and experimental investigations:

- The base isolation device must possess an effective re-centering mechanism, sufficient shear resistance, suitable vertical stiffness, and the ability to dissipate the energy generated by seismic forces. Additionally, it should maintain its mechanical characteristics throughout the service life of the base isolation systems. The selection of the seismic isolation system type is contingent on the specific structure undergoing retrofitting, such as masonry structures, historical monuments, buildings, bridges, liquid retaining structures, etc. Additionally, the design must account for the structural implications of any long-term changes in the properties of the base isolation system.

- The hysteresis curves of HDRB show a smaller area compared to LRB, indicating an unexpected lower energy dissipation capacity under similar shear deformation conditions. The horizontal shear performances of both types of bearings are illustrated in the force-displacement curve LRB and HDRB, indicating that the HDRB has a lower horizontal stiffness than the LRB under equivalent vertical loading and shear strain. This implies that, with an equal total rubber thickness, the steel plates in the HDRB exert less constraint force on the rubbers compared to the lead core in the LRB. The presence of the lead core enhances the energy dissipation capacity of the LRB.
- The study in Chapter 3 validates that both isolators significantly diminish the effects of earthquakes, with LRB showing superior performance over HDRB. The maximum reductions in response are 68.42% for the Kocaeli earthquake in the case of LRB and 61.80% for the Northridge earthquake in the case of HDRB. The reduction in acceleration response at the top of the bearing is indicative of the bearings' effectiveness in mitigating the impact of seismic forces on the structure. This emphasizes their pivotal role in enhancing the collective seismic performance and safety of the structure.
- In influence of near field ground motion excitation, the peak displacement for LRB under the Imperial Valley ground motion is 62.577mm, while for HDRB under the Managua earthquake record, it is 221.052mm.

- The Chapter 4 highlights the use of HDRB and LRB in the isolation system effectively reduces base shear forces. Specifically, the introduction of isolators in the a 10-story RC frame building leads to a noticeable reduction in base shear. For instance, under near-field conditions, the maximum reduction in base shear is 38.37% during the Northridge earthquake. Similarly, under far-field conditions, the maximum reduction is 35.65% during the Chi-Chi earthquake.
- The acceleration response of a 10-story RC building is generally highest at the top floors in both fixed-base and isolated-base structures. However, the BI frame demonstrates a substantial reduction in these responses. In near-field conditions, the acceleration response reduction at the top floor is 65.28% during the Loma Prieta earthquake. In far-field conditions, the reduction is even more significant at 71.53% during the Imperial Valley earthquake, compared to the fixed-base analysis.
- The base displacement of a 10-story isolated RC building during the Imperial Valley earthquake is 110.6 mm under near-field conditions and 105.8 mm under far-field conditions.
- Chapter 5 presents an experiment evaluating the effectiveness of a sliding base isolation system by testing individual and combined configurations of linear and nonlinear springs. The performance was compared with that of a fixed-base system to assess improvements.
- An Impact Hammer Analysis is conducted to determine frequency responses, generating a Frequency Response Function (FRF) curve for different modes. The FRF results are closely aligned with ABAQUS analysis.

- The force-displacement curve for a low-stiffness linear spring was generated numerically using SOLIDWORKS and experimentally using a UTM machine. The results showed strong agreement between the numerical and experimental data.
- A three-story moment-resisting frame is analyzed to evaluate its responses under both fixed-base conditions and sliding-base systems with spring combinations, focusing on acceleration and maximum inter-story drift ratio (IDR). The analysis demonstrates a significant reduction in these responses when using the sliding base with springs, highlighting its effectiveness compared to the fixed-base configuration.
- The experiment analyzed five combinations-FB, SB, SB+CS, SB+LS, and SB+HS-at 25 mm and 45 mm amplitudes across varying frequency levels. For an amplitude of 25 mm, the SB configuration achieves a maximum acceleration reduction of 37.61% at 0.79 Hz, while the SB+CS combination performs best at 0.98 Hz with a 47.32% reduction, highlighting the cushioning spring's damping enhancement. The SB+LS combination is most effective between 1.24-1.36 Hz, achieving a 34.56% reduction at 1.36 Hz. At 1.63 Hz, acceleration response becomes negligible, but toppling effects arise, indicating stability concerns. The SB+HS combination shows a lower reduction of 19.83%, suggesting limited effectiveness at higher frequencies. Numerical simulations closely match experimental results, validating the findings. For an amplitude of 45 mm, acceleration reduction peaks at 50.91% at 1.24 Hz, but instability prevents testing beyond this frequency, confirming the system's limitations at higher amplitudes.

6.3 Potential Future Scope

Recent advancements in seismic base isolation have made significant progress, yet there remain several areas remains for further investigation. Here are some important areas which needs further deep exploration:

- Future research in the analysis of HDRB and LRB using Abaqus should emphasize the development of accurate material models, enhancements in contact algorithms, and the refinement of dynamic loading simulations. Incorporating viscoelastic properties alongside other hyperelastic material models (like Aruda Bouce, Ogden, Yeoh model, etc.) could be simulated numerically to identify the most optimized and improve models with enhanced precision and accuracy. It is crucial to conduct comprehensive experimental studies and parametric analyses to validate results and gain insights into the impact of various design parameters.
- Severe deformations in bearings during strong tremors can impair their long-term function. Research is needed to develop accurate models and robust testing for predicting performance under substantial deformation. Bearings may lose elasticity due to compression set, particularly affecting structures with low-frequency vibrations. Improved installation and maintenance methods are essential. More rubber layers enhance horizontal flexibility and reduce seismic amplification, concentrating displacements at the isolator level and minimizing damage to structural components.
- Future research should use finite element micromodels to examine the stress, strain, and strength of LRB, HDRB, and sliding bearings to improve design accuracy. It should be crucial to address lead core heating and rubber buckling problem. The lead core in LRB

notably impacts stress distribution, while dynamic analysis in Abaqus faces challenges with material models, large deformations, and contact modeling.

- The friction between the sliding plates of devices is a primary source of heat generation. Therefore, it is essential to develop materials that are highly durable under cyclic loading conditions and minimize heat generation while maintaining the initially recorded friction value.
- Future work should explore the application of seismic sliding base isolation combined with spring mechanisms to assess the stability and behavior of water tanks positioned on various stories of a structure. This investigation would focus on identifying the most optimal and stable placement of water tanks, evaluating their response under a range of seismic intensities from minor to extreme events. Such an approach aims to enhance the resilience of critical water storage systems by mitigating seismic impacts, ensuring functionality, and minimizing potential risks in seismic-prone regions.
- Future research should aim to enhance the seismic performance of piled raft foundations with isolators by thoroughly investigating the integration of inertial and kinematic interactions. This approach will help better understand how these interactions affect the system's response.
- Future research should focus on cost-effective, practical solutions for real-world structures, going beyond small-scale models and numerical simulations. Comprehensive studies should include both numerical simulations and experimental analyses of various isolation systems, such as bearings combined with modern supplemental damping devices. This will deepen the understanding of isolator responses and properties, ensuring their effective application in real structures. Ongoing advancements in base isolation are

enhancing its reliability and efficiency, making it a sustainable, economical choice for diverse construction projects.

- Future research could examine the long-term durability and maintenance of isolation systems, as well as their effectiveness in diverse soil and structural conditions, could provide valuable insights. Expanding field studies and large-scale tests will also be crucial in validating theoretical models and improving practical applications of seismic base isolation systems.

In summary, these ideas indicate crucial research areas essential for advancing our understanding of base isolation systems. Key areas include refining accurate modeling techniques, assessing long-term sustainability, evaluating mechanical performance under challenging conditions, and investigating dynamic loading effects. Additionally, exploring innovative rubber materials will enhance the design and construction of isolators, leading to safer, more efficient, and environmentally friendly solutions.