

CHAPTER 1 INTRODUCTION

1.1 General Theory

Earthquake engineering is a crucial discipline aimed at protecting society from the devastating effects of seismic events by designing, analyzing, and constructing structures that can withstand and perform adequately during and after earthquakes. An earthquake occurs when energy is suddenly released in the Earth's lithosphere due to tectonic plate movements, generating seismic waves. Understanding seismic activity is essential for developing earthquake-resistant designs, early warning systems, and emergency preparedness, as well as for assessing risks, enhancing public safety, and advancing geophysical knowledge. Historically, earthquakes have shaped cultures, influenced urban development, and contributed to the development of plate tectonic theory. Seismic activity often occurs along plate boundaries—divergent (plates moving apart), convergent (subduction zones), and transform (plates sliding past each other). Faults are classified as normal (extensional), reverse (compressional), or strike-slip (horizontal motion). Earthquakes produce P-waves (fast, compressional), S-waves (slower, shear), and surface waves (destructive, traveling along the surface). Earthquakes have repeatedly demonstrated their devastating potential throughout history, leaving a lasting impact on communities and the built environment. Among the most notable in history as shown in the Table 1.1.

Table 1.1 List of the measure earthquakes in history

Earthquake Name	Magnitude	Location	Country	Year	Loss of Life
Shaanxi Earthquake [1]	8.0	Shaanxi	China	1556	830,000
Lisbon Earthquake [2]	8.5	Lisbon	Portugal	1755	62,000

Koyna Earthquake [3]	6.5	Koyna	India	1967	200
Tangshan Earthquake [4]	7.6	Tangshan	China	1976	242,000
Loma Prieta Earthquake [2]	6.9	Loma Prieta	USA	1989	63
Northridge Earthquake [2]	6.7	Northridge	USA	1994	57
Kobe Earthquake [5]	6.9	Kobe	Japan	1995	6,000
The Kocaeli Earthquake [2]	7.6	Kocaeli	Turkey	1999	17,118
Chi-Chi Earthquake [5]	7.7	Chi-Chi	Taiwan	1999	2,297
Gujarat Earthquake [6]	7.7	Gujarat	India	2001	20,000
Kashmir Earthquake [7]	7.6	Balakot	Pakistan	2005	87,351
Yogyakarta Earthquake [8]	6.4	Yogyakarta	Indonesia	2006	5,749
Sichuan Earthquake [9]	8.0	Sichuan	China	2008	70,000
Tohoku Earthquake [10]	9.1	Tohoku	Japan	2011	20,000
Nepal Earthquake [11]	7.8	Gorkha	Nepal	2015	9,000

The devastation caused by earthquakes throughout history serves as a stark reminder of the immense power and unpredictability of these natural disasters. Entire cities have been reduced to rubble in a matter of seconds, with lives lost and communities shattered. Iconic examples include the 1906 San Francisco earthquake, which leveled much of the city and ignited fires that burned for days, and the 2010 Haiti earthquake, which claimed hundreds of thousands of lives and left millions homeless. The destruction extends beyond physical infrastructure, affecting economic stability, social structures, and the mental well-being of

survivors. These events underscore the critical need for continued research, preparedness, and resilient design to mitigate the catastrophic impact of future earthquakes.

The foundation of earthquake engineering lies in understanding the complex interactions between seismic forces and the built environment. This involves the study of ground motion characteristics, the behavior of materials under dynamic loads, and the development of innovative design and construction techniques. Engineers employ a range of methodologies, including seismic hazard assessment, structural dynamics, and advanced computational modeling, to predict and enhance the performance of structures during earthquakes.

1.2 Introduction of Base isolation

Among various natural disasters and undesirable shakings, earthquakes stand out as the most harmful and perilous occurrences, leading to significant loss of human lives and widespread destruction of infrastructure. Tackling this daunting challenge poses a significant hurdle for structural designers and engineers. Extensive research, analysis, and experiments have led to the development of diverse strategies aimed at mitigating the effects of ground motion on structures, thereby strengthening the seismic capacity of structures. Among the available seismic protection methods, base isolation is the predominant seismic protection technology due to its stability, application and reliability [12].

The base isolation technique is not recent; it has historical roots and was widely employed in ancient structures, including Chinese monasteries, bridges, temples, and walls. Early constructions used layers of materials, predominantly clay mixed with ashes and charcoal, allowing relative movement between the foundation and the ground during seismic

activity [13]. Over the course of history, comprehensive analyses have explored into the origin, development, and application of seismic BI technology. Extensive research has been conducted on critical structures, such as hospitals, storage vessels, nuclear power plants, and fire stations that require protection from ground motion-induced damage, particularly due to their sensitivity to vibrations. It has been observed that implementing an isolation system can enhance the seismic capacity of these structures to a considerable extent [14].

1.2.1 Basic Mechanism

Base isolation is pivotal for seismic hazard mitigation, focusing on structural safety and sustainability. Among the numerous approaches, the development of base isolation techniques is notable—raising buildings from the ground with flexible foundations to minimize force and motion transmission [15]. The detailed study [16] regarding the dynamic behavior of the structures concludes that resonance significantly intensifies the probability of severe destruction, which occurs when the natural vibrating frequency of the building approaches the dominant frequency of seismic excitation. The fundamental notion of base isolation entails isolating the superstructure from the harmful effects of ground motion by incorporating isolators between the superstructure and foundation, as shown in Figure 1.1 [17][18]. Increasing the time-period of the structure results in larger relative displacements, as depicted in Figure 1.2. Decoupling aims to lengthen the structural period, as shown in Figure 1.3, thereby preventing resonance with the frequencies of unwanted vibrations or earthquakes [19]. Eventually, it minimizes acceleration and lateral forces, exerting control over the structural response. Reduced seismic demand preserves superstructure elasticity, lowering the risk of damage to sensitive equipment and non-structural elements. Effective isolation devices must exhibit key characteristics, including the capability to withstand superstructure dead load,

adequate lateral flexibility, accommodation of displacements, and incorporation of proper mechanisms for energy dissipation. They should also have the ability to withstand minor seismic activity while dissipating energy during high-intensity earthquakes. The material and device properties should adequately represent behavior under design conditions, consider environmental factors throughout the device lifespan, and account for aging phenomena. Extensive research over recent decades has expanded the literature on base isolation, with numerous reviews covering its development, theory, and application [20][21].

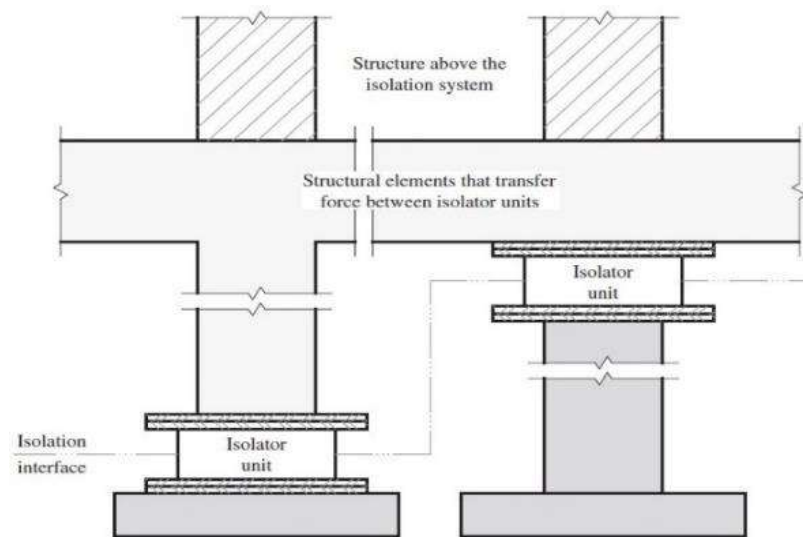


Figure 1.1 Base Isolation Terminology (ASCE 7-16)

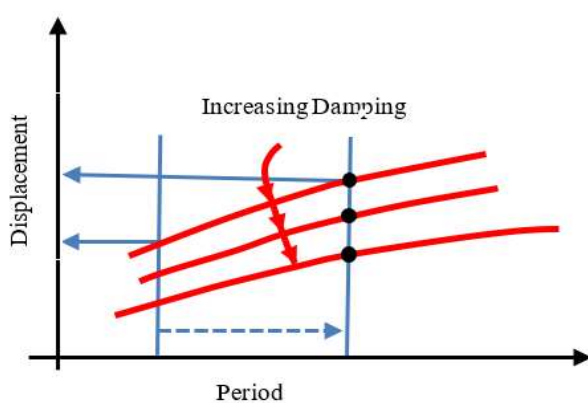


Figure 1.2 Displacement design response spectra

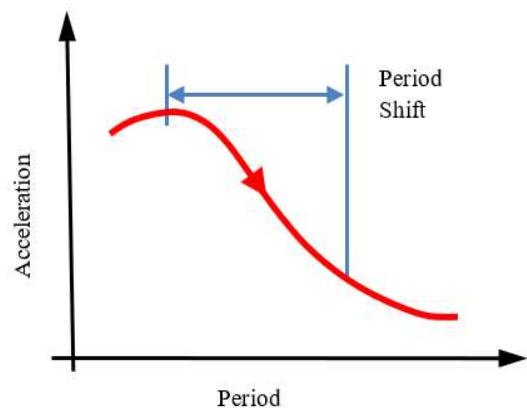


Figure 1.3 Time Period Shift

1.2.2 Historical Development

Around 530 BCE, Persia used a basic sliding system for the Tomb of King Cyrus, allowing stone blocks to slide without mortar. In Corinth and Ephesus, around 540 BCE and 120 CE, monolithic columns atop rock were used to construct the Temple of Apollo and the Library of Celsus, respectively. The Obelisk of Theodosius, originally constructed in Egypt in 1450 BCE, was relocated to Constantinople and positioned in the hippodrome on a marble pedestal equipped with pivoting supports and a movable base [22]. The historical origins of the modern form of the base isolation system can be traced back to 1870, when a double concave spherical sliding-bearing base isolation system, similar to the current double concave FPS (Friction Pendulum System), was patented in San Francisco, USA [23]. The base isolation technique was first proposed in Japan in 1894 and implemented in 1934 in two bank structures using the Knee-Joint isolation mechanism below the columns [24]. In 1909, Dr. Calantarients proposed a seismic isolation technique, i.e., a sliding isolator using talc or mica layers. A 1933 building in Ljubljana, Slovenia, demonstrated early seismic isolation with metal and asphalt layers. The Pestalozzi school in Skopje, Yugoslavia, implemented base isolation in 1969 using unreinforced rubber blocks. However, these blocks lacked vertical stiffness, causing undesired vertical acceleration and a bouncing effect, rendering them unusable [25]. Over the past four decades, various seismic isolation devices, including roller bearings, elastomeric bearings, rubber bearings, sliding bearings, and frictional bearings, have been developed to control the dynamic response of structures. Rolling-type isolators employ balls or rolling rods that can crisscross on concave surfaces. The arrangement of these rolling surfaces determines the displacement-dependent restoring force [26]. The modern Friction Pendulum tackles concerns related to low-friction materials, heating effects, contact pressure, and velocity. Following this, the subsequent research introduces Double Concave Friction Pendulum and Triple

Friction Pendulum bearings [15]. Elastomeric isolators, comprising rubber sheets with vulcanised reinforcement (steel or fibers), vary based on damping characteristics [27]. This type of bearing is classified as Low damping elastomer isolators are labeled LDRB [28], high damping elastomer isolators as HDRB [29], those with a lead core for increased damping as LRB, and those with rigid fiber reinforcement as FREB [30]. In recent decades, using reliable devices like elastomeric or sliding isolators, BI has gained prominence for reducing earthquake-induced losses. Numerous scholars have suggested innovative approaches to attain adaptive functionality in isolators, encompassing elastomeric and sliding mechanisms.

1.2.3 Recent Developments

The escalating concerns about the recent rise in earthquake intensity have driven researchers to improve and advance the capabilities of existing seismic isolation devices while also developing new ones. Recent advancements in sustainable low-cost materials for seismic isolators, such as the Geotechnical Seismic Isolation (GSI) system that uses shredded rubber-soil mixtures, offer a cost-effective solution to reduce earthquake-induced structural response. This system enhances safety in less-developed regions and addresses the global waste tire issue, showing significant potential in mitigating seismic hazards [31]. Eco-friendly Scrap Tyre Rubber Pads (STRPs) provide a cost-effective, easily adjustable solution for shear stiffness and contribute to recycling efforts. Experimental assessments of STRP properties, crafted with thin steel shims between rubber pads and subjected to vulcanization, included axial compression tests and horizontal shear tests. The STRP isolator, crafted from radial tires, has a damping ratio of 18.48%, surpassing the 3.5% damping ratio found in natural rubber bearings. This higher damping ratio suggests the potential to eliminate additional enhancements up to a specified level [32].

An experimental study found that a thick layer of compressible limestone sand under a cantilever concrete column's foundation can act as a seismic base isolator [33]. Another smart base isolation system that adjusts its properties when triggered by an Earthquake Early Warning (EEW) signal was developed in Japan. Under normal conditions, the system is locked by shear keys, and when an earthquake is detected, a mechanical mechanism releases it [34]. Apart from these innovations, recycled rubbers are also employed as isolator materials. The "composite foundation" concept impeccably integrates seismic metamaterials with a structure foundation to reduce energy transfer from seismic waves within the frequency range associated with the first vibration mode [35]. This innovative approach marks a paradigm shift in seismic protection design, particularly emphasizing S-waves and their associated high amplitudes. With the advent of new research, isolation methods, including sand layers and thermal insulation boards, have evolved for seismic protection. A recent study [26] investigates the application of thermal insulation boards for cost-effective sliding prevention.

Base isolation, a technique designed to mitigate earthquake forces, encounters various challenges, including high costs, intricate design demands, ongoing maintenance requirements, limited applicability to specific structures, uncertainties in seismic input, sensitivity to construction quality, integration issues with existing structures, and public acceptance concerns. Despite these obstacles, base isolation remains invaluable for enhancing seismic strength, particularly in high-risk areas. Ongoing research endeavors seek to refine its effectiveness continually.

While numerous review articles on base isolation systems exist [26], [36] few probes into various aspects collectively. In this study, various aspects of base isolation are reviewed, including outline commonly employed seismic isolation system, modeling techniques,

numerical simulation software, retrofitting and rehabilitation of old structures, effects of soil-structure interaction, 3D isolator modeling considerations beyond design events (such as the impact of aircraft and blast loading on structures), assessments specific to nuclear power plants, cost analysis, optimization effects, and document the historical evolution of contemporary seismic BI through scaling and shake table experiment of isolated structure. The exploration of these advanced aspects is limited, as the majority of shake table tests predominantly concentrate on horizontal ground motion. The research contrasts a conventional structure with a base-isolated one to evaluate the effectiveness of the base isolation technique. Further, the aspects in conjunction with the advantages and disadvantages of various isolators, code recommendations, and includes relevant case studies. Furthermore, tracing its historical evolution over a century, the review evaluates recent technological advancements, including innovative materials and adaptive systems. By presenting a nuanced perspective on the strengths and limitations of the base isolation, the review chapter contributes to the ongoing discourse in seismic engineering. The assessment ends with closing remarks and a study of potential future actions.

1.3 Organization of the Thesis

The present work is organized into the following chapters:

Chapter 1 provides an introduction, emphasizing the importance of mitigating earthquake-induced responses and introducing the concept of seismic base isolation as an effective solution. Additionally, the chapter presents the organization of the thesis, summarizing the contents of the following chapters, including the literature review, methodology, analysis, results, and conclusions, to offer a comprehensive understanding of the research conducted chapter wise.

Chapter 2 presents a comprehensive literature review relevant to the current research, focusing on the development of various seismic isolators, with an emphasis on analytical, numerical, and experimental methods. It outlines the research objectives, which aim to address key gaps by analyzing isolators and structures under different seismic conditions. It examines case studies, recent advancements, and emerging trends, while identifying potential future research areas to advance the field further.

Chapter 3 focuses on comparing the dynamic performance of passive base isolators, specifically High Damping Rubber Bearing (HDRB) and Lead Rubber Bearing (LRB), under near-fault ground motions to evaluate their effectiveness in mitigating seismic impacts on structures. Both the isolators are analyzed using a static general approach and validated against results from existing literature. The seismic performance of these isolators is studied under various ground motions, such as Imperial Valley, Managua, Loma Prieta, Northridge, and Kocaeli earthquakes.

Chapter 4 presents a comparison of the responses of a reinforced concrete (RC) frame building equipped with base isolation to those of a fixed-base structure when subjected to near-field (NF) and far-field (FF) earthquake records. The selected records are from the Imperial Valley, Loma Prieta, Northridge, Kobe, and ChiChi earthquakes. The study employs HDRB and LRB as the seismic isolation devices. Using SAP2000, a base-isolated (BI) building model was developed and subjected to nonlinear time history (NLTH) analysis to evaluate the buildings response during NF and FF earthquake events.

Chapter 5 evaluates the performance of a fixed base structure and structure isolated by sliding bearings combined with and without linear and nonlinear restoring springs through experimental testing and numerical verification of the experimental results of some model

using ABAQUS software. This study involves five types of analyses: fixed base, sliding base, sliding base with a low-stiffness linear spring, sliding base with a high-stiffness linear spring, and sliding base with a nonlinear spring. The results are compared across various parameters.

Chapter 6 concludes the thesis by reviewing essential discussion, providing practical recommendations, and proposing potential future study fields. It highlights the study's contributions, notably in terms of improving seismic isolation design and performance under varying seismic circumstances. The chapter also emphasises the necessity of future study on isolator optimisation and long-term performance, presenting an overview of the findings and their implications for seismic base isolation.