DEVELOPMENT OF PROBABISLISTC SEISMIC HAZARD ASSESSMENT FOR NORTH WESTERN MOUNTAINOUS REGION, HIMACHAL PRADESH

A
PROJECT REPORT
Submitted in partial fulfilment of the requirements for the award of the degree

Of

BACHELOR OF TECHNOLOGY
IN
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Under the supervision

of

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by

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to

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WAKNAGHAT, SOLAN – 173234
HIMACHAL PRADESH, INDIA
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STUDENT'S DECLARATION

We hereby declare that the work presented in the project report entitled **"Development of Probabilistic Seismic Hazard Assessment for North Western Mountainous Region, Himachal Pradesh"** submitted for partial fulfilment of the requirements for the degree of Bachelor of Technology in Civil Engineering at **Jaypee University of Information Technology, Waknaghat** is an authentic record of our work carried out under the supervision of **Dr. Saurav**. This work has not been submitted elsewhere for the reward of any other degree/diploma. We are fully responsible for the contents of this project report.

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CERTIFICATE

This is to certify that the work which is being presented in the project report titled **"Development of Probabilistic Seismic Hazard Assessment for North Western Mountainous Region, Himachal Pradesh"** in partial fulfilment of the requirements for the award of the degree of Bachelor of Technology in Civil Engineering submitted to the Department of Civil Engineering, **Jaypee University of Information Technology, Waknaghat** is an authentic record of work carried out by **Deepak Thakur (191604)** during a period from August, 2022 to May, 2023 under the supervision of **Dr. Saurav, Assistant Professor (SG)**, Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.

The above statement made is correct to the best of my knowledge.

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Deepak Thakur (191604)

TABLE OF CONTENTS

Chapter 1 Introduction

Chapter 2 Literature Review

Chapter 3 Methodology

Chapter 4 Results and Discussion

Chapter 5 Conclusion

LIST 0F TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Abbreviations	**Full form**
PSHA	Probabilistic Seismic Hazard Assessment
DSHA	Deterministic Seismic Hazard Assessment
NW	North Western
NCS	National Centre for Seismology
MBT	Main Boundary Thrust
HFT	Himalayan Frontal Thrust
MCT	Main Central Thrust
STDS	South Tibetan Detachment System
IMD	Indian Meteorological Department
PHA	Peak Horizontal Acceleration
PHV	Peak Horizontal Velocity
PHA	Peak Ground Acceleration
PSA	Peak Special Acceleration
PGA	Peak Ground Acceleration
PSV	Pseudo Spectral Velocity
PSA	Pseudo Spectral Acceleration
GMPEs	Ground Motion Prediction Equations

ABSTRACT

The Himalayan Mountain range is one of the most significant tectonic structures thought to have been created by the collision of two continents as a result of the relative movement of plates (Dewey and Bird, 1970). The Western Himalayas, also known as the Northwest (NW) Himalaya, is located between the latitudes of 30-33 degrees North and the longitudes of 75-78 degrees East. This area is seismically active and is classified as belonging to seismic zones IV and V on the India hazard zonation map. The Indian plate is still moving to the north, which is creating a lot of tension at the plate boundary that is being released in the form of massive and powerful earthquakes. There should be a focused study on seismic hazard assessment since growth connected to building is growing. This study presents comprehensive research on probabilistic seismic hazard analysis for mountainous regions. The source zones are accounted for by local variation in tectonics and seismicity characteristics. The seismicity parameters are estimated for each of these source zones, which are input variables into seismic hazard estimation of a region. PSHA, or probabilistic seismic hazard analysis, is a crucial instrument for evaluating seismic risks in earthquake-prone areas. Himachal Pradesh is a seismically active area in the Himalayan region and has previously seen a number of significant earthquakes. In order to assess the risk of earthquakes and establish the ground motion characteristics for various locations, PSHA has been done in Himachal Pradesh. The PSHA data demonstrate that the Himalayan thrust system, which causes the majority of earthquakes in the area, is principally responsible for controlling the seismic hazard in Himachal Pradesh. The PSHA study also identified the regions most susceptible to seismic risks, and this knowledge may be utilised to create strategies for earthquake mitigation and readiness. Overall, the PSHA research offers useful data on the seismic risks in Himachal Pradesh and can help with the creation of practical plans to lower the danger of earthquakes there.

Results obtained in the present study would be helpful for risk assessment and other disaster mitigation-related studies. Also, it can be used as tools to quantitatively assess the earthquake risk across India and also compare with other countries to develop risk-informed building design guidelines, for more careful land use planning, to optimize earthquake insurance pricing, and to enhance general earthquake risk awareness and preparedness.

Keywords– Seismic hazard assessment, north western India, peak ground acceleration

CHAPTER 1

INTRODUCTION

1.1 General

Since the Indian and Eurasian plates collided, the Himalayan Mountain range has experienced significant seismic activity. The area is vulnerable to earthquakes of different magnitudes, many of which cause serious harm to people and property. Several earthquakes have previously occurred in the north western mountainous region of Solan, Himachal Pradesh, which is situated in this active seismic zone. Conducting a probabilistic seismic hazard assessment to determine the potential ground motion at the study site is crucial given the high seismic risk in the area. Building codes, design standards, and emergency response plans for the area can all be informed by the evaluation, which can also provide essential information for disaster management and mitigating seismic risk. Numerous geological, seismological, and geotechnical data were gathered from various sources in order to carry out the probabilistic seismic hazard assessment. It was decided to use the Cornell-McGuire method, which entails hazard curve construction, calculation of earthquake parameters, catalogue compilation, identification of possible seismogenic sources, and ground motion prediction equation formulation. According to the assessment's findings, the research area has a high seismic risk of ground shaking that exceeds the levels intended for various engineering constructions. This conclusion emphasises the necessity for disaster management planning and seismic risk mitigation in the area. The overall goal of this paper is to offer crucial knowledge on the seismic risk in the northwest mountainous area beneath Solan, Himachal Pradesh, so that it may be used to create efficient risk mitigation measures and emergency response plans. The results of the study can also be used to inform design standards and construction rules to guarantee that upcoming engineering structures in the area are constructed to resist seismic activity.

1.2 Geological Setting

Himachal Pradesh, which is in the Himalayan Mountain range and is recognised for having a high seismic activity, is situated in the northwest of India. The area is located in a tectonically active zone where the Indian plate and the Eurasian plate are interacting. This collision makes the area a seismically active zone because it frequently creates earthquakes there. In Himachal Pradesh, numerous earthquakes have been registered during the last few decades. The 1905 Kangra earthquake, which was estimated to have had a Richter magnitude of 7.8, was one of the most important quakes to happen in the area. Over 20,000 people lost their lives as a result of this earthquake, which also significantly damaged property.

Figure 1.1 1905 Kangra Earthquake

There have been a few of moderate- to low-intensity earthquakes in the area recently. The Kinnaur district experienced an earthquake on January 6, 2021, with a magnitude of 3.7, according to the National Centre for Seismology (NCS). On December 12, 2020, a second earthquake of a magnitude of 2.5 was observed in the Mandi district. Despite their smaller size, these earthquakes serve to highlight the need for ongoing monitoring and the considerable seismic activity in the area.

Figure 1.2 Earthquake of magnitude 2.5 was reported in Mandi district on December 12, 2020

The Indian government has installed various seismic stations around Himachal Pradesh in order to track and analyse the seismic activity in the area. The seismic stations are outfitted with sophisticated equipment that can pick up even the smallest earthquakes in the area and record them. The information gathered from these seismic stations is utilised to research the local seismic activity and create early warning systems for earthquakes.

Seismology and earthquakes in Himachal Pradesh serve as a continual reminder of the area's high seismic activity and the importance of ongoing monitoring and readiness to reduce earthquake risks.

1.2.1 Importance of seismic hazard assessment

Planning for earthquake risk management and catastrophe mitigation must include seismic hazard assessment. Important details concerning the chance of an earthquake happening in a particular area, the strength of the ground shaking, and the possible harm to buildings, infrastructure, and people are all provided by the assessment. Here are some major arguments in favour of the significance of seismic hazard assessment:

1. Prevents loss of human life by identifying places most at risk for earthquake destruction through seismic hazard assessment. In the case of a significant earthquake, this information can be utilised to guide emergency response preparations and evacuation protocols, potentially saving lives.
2. Limits property damage: By comprehending an earthquake's possible effects, building rules and construction standards may be devised to limit damage to infrastructure and buildings, lowering the economic toll of earthquakes.
3. Lowers insurance costs: Seismic hazard assessment gives insurance firms crucial information for evaluating risk and determining rates. Insurance costs for households, companies, and governments can be decreased with accurate seismic hazard assessment.
4. Facilitates efficient planning: Data from seismic hazard assessments may be utilised to guide infrastructure and land-use planning decisions. This can make sure that new construction is situated in places that are less vulnerable to earthquake damage.
5. Seismic hazard assessment offers important information for earthquake researchers, enabling them to better understand the seismic activity in a particular location and enhance earthquake forecasting models. 5. Supports earthquake research.

1.2.2 Historical earthquakes in the region

Due to its closeness to active tectonic zones, Himachal Pradesh in India's north-western Himalayan area is extremely vulnerable to earthquakes. The following are a few of the region's most notable historical earthquakes:

1. A significant earthquake measuring 7.8 on the Richter scale rocked the Kangra region in Himachal Pradesh on April 4, 1905. Over 20,000 fatalities were reported, and the earthquake severely damaged infrastructure and buildings. The earthquake was one of the worst seismic occurrences in the Indian subcontinent's history.
2. The Kinnaur earthquake of 1975: On January 19, 1975, an earthquake of a magnitude of 6.8 jolted the Himachal Pradesh area of Kinnaur. With over 60 confirmed deaths, the earthquake severely damaged infrastructure and structures.
3. 2013 Mandi earthquake: On June 23, 2013, a 4.6-magnitude earthquake shook the Himachal Pradesh area of Mandi. No fatalities were reported, however the earthquake did inflict minor damage to infrastructure and structures.

4. The 2015 Chamba earthquake: On November 8, 2015, a magnitude 5.0 earthquake shook the Himachal Pradesh area of Chamba. No fatalities were reported, however the earthquake did inflict minor damage to infrastructure and structures.
5. The 2018 Dharamshala earthquake: On September 23, 2018, a magnitude 3.6 earthquake hit the Himachal Pradesh area of Dharamshala. No fatalities were reported, however the earthquake did inflict minor damage to infrastructure and structures.

The seismic activity in the area and the potential dangers to infrastructure and human life are highlighted by these previous earthquakes. Understanding the seismic hazard and risk assessment of the area is crucial for creating earthquake-resistant designs for infrastructure, buildings, and other structures. This may be done by studying prior earthquakes.

An earthquake is a tectonic plate's movement or collision which takes place naturally. Earthquakes happen because of the movement and collision of tectonic plates. The energy produced by the collisions travels through and across the earth's surface as seismic waves. These waves, which travel in all directions, are referred to as body waves or surface waves.

1.2.3 Tectonic setting of the region

Himachal Pradesh is located in the Himalayan orogenic zone in the northwest of India. The collision of the Indian and Eurasian plates has created a complicated tectonic environment in the area. The continuous India-Asia collision, which started around 50 million years ago and continues now, is thought to be responsible for the region's tectonic development.

The subduction of the Indian plate under the Eurasian plate, which resulted in the elevation of the region and the construction of towering peaks, deep valleys, and steep slopes, is what created the Himalayan Mountain range. Thrust faulting, which is caused by the compression of the Indian plate against the Eurasian plate, is another feature of the area.

Sub-Himalaya, Lesser Himalaya, Higher Himalaya, and Trans-Himalaya are some of the tectonic divisions of the Himalayan orogenic belt. The Lesser Himalaya, where Himachal Pradesh is situated, is made up of intricate geological features such thrust faults, folds, and shear zones.

The Main Boundary Thrust (MBT), the Himalayan Frontal Thrust (HFT), the Main Central Thrust (MCT), and the South Tibetan Detachment System (STDS) are only a few of the active tectonic zones that have an impact on the area. These areas have a record of multiple earthquakes in the area and are marked by significant tectonic activity.

Himachal Pradesh's geological environment is intricate, and the area is particularly vulnerable to earthquakes. In order to estimate the seismic risk and hazard in the area and create earthquake-resistant designs for buildings, infrastructures, and other structures, it is crucial to understand the region's geological context.

1.2.4 Previous seismic hazard studies in the region:

Over the past few decades, the Himachal Pradesh region has been the subject of numerous seismic hazard studies. These studies have used a range of procedures, from probabilistic to deterministic, to evaluate seismic danger.

The Indian Meteorological Department (IMD) carried out one of the first seismic hazard assessments in the area in the 1970s. The study calculated the largest credible earthquake magnitude for the area using a deterministic methodology. The regional heterogeneity of seismicity and ground motion attenuation, however, was not taken into account in the study.

A seismic microzonation study was carried out in 2003 for the Himachal Pradesh city of Shimla. The study calculated the city's seismic danger using both deterministic and probabilistic methods. The study generated ground motion prediction equations for the area and identified probably seismogenic sources. The research also identified high-risk areas in the city and suggested construction rules and seismic safety standards for construction.

Another probabilistic research of the region's seismic threat was carried out in 2013. The research quantified the seismic danger for the area using the Probabilistic Seismic danger Analysis (PSHA) proximity. The study generated ground motion prediction equations for the area and identified probable for diverse engineering buildings the research also calculated the yearly possibility of exceeding ground motion.

These studies have some limitations, despite the fact that they offer insightful information on the region's seismic danger. For instance, the geographical heterogeneity of seismicity and ground motion attenuation was not taken into account in the prior investigations. The availability of data, such as the seismic catalogue and geotechnical data, is constrained in more recent investigations.

By addressing these issues, the current study hopes to provide a more accurate and trustworthy seismic hazard assessment for the northwest mountainous area that lies under Solan, Himachal Pradesh. The analysis uses a probabilistic methodology and takes into account the ground motion attenuation and seismicity's geographical variability. In order provide a more accurate and reliable assessment of seismic danger in the area, this study also makes use of the latest and most recent seismic and geotechnical data.

1.3 Ground Motion

The energy that was "saved" in heavy rocks and released when a fracture cracked and the rocks slipped to release the pent-up strain causes the Earth to vibrate when earthquake waves sweep across it. The rate of ground motion, its acceleration, its frequency content, and its length (the "period") are all used to calculate the strength of floor cracking. How frequently significant movement is expected to recur is a crucial factor to take into account when assessing the capacity shaking risk for an area in particular. Although there are numerous factors that can cause ground shaking (such as volcanic tremors, avalanches, large explosions, etc.), earthquakes tend to be to blame when it is sufficiently severe to cause harm.

The "size" or "strength" of the source event as measured by various seismic magnitude scales.

- The intensity or depth of the occurrence;
- The kind and orientation of the seismic wave.
- The separation from the first incident.
- Site response brought on by local geology.

Because some factors, like unconsolidated sediment in a basin, can multiply ground vibrations by ten, site response is crucial.

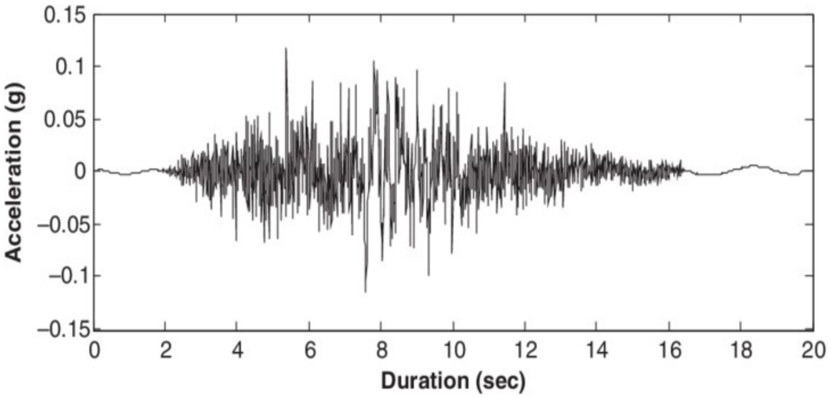


Figure 1.3 Time history of a design earthquake ground motion PMA

1.3.1 Ground Motion Parameter

Ground motion parameters are essential for a brief, numerical illustration of the significant characteristics of strong ground motion.

A group of evaluates or parameters that are used to define the features of ground motion during an earthquake are referred to as ground motion parameters. For seismic hazard assessments, earthquake engineering, and the construction of earthquake-resistant structures, ground motion characteristics are essential.

In earthquake engineering and seismic hazard assessments, a number of ground motion characteristics are frequently applied.

Measurements of amplitude The most basic way to depict a ground motion is through a time history. velocity, displacement, or a combination of these three

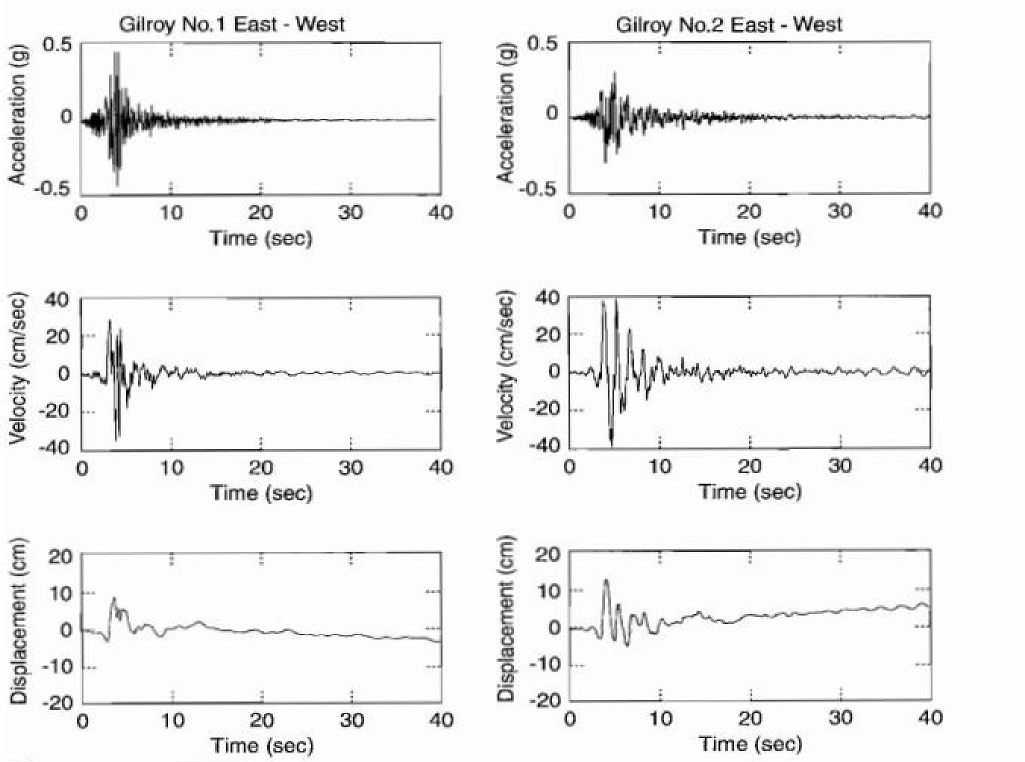


Figure 1.4 Acceleration, velocity, and displacement E-W components of the Gilroy Iand GilroyII strong motion records.

Maximum Acceleration The most common method used to determine the magnitude of a ground motion is to use the peak horizontal acceleration (PHA). The PHA for a certain component of motion is the highest (absolute) value of horizontal acceleration as derived from the accelerogram of that component.

Peak Speed Peak horizontal velocity (PHV) is another helpful metric for determining the size of ground motion. Because the velocity is less sensitive to the higher-frequency components of the ground motion, the PHV is more likely than the PHA to define ground motion frequency correctly at intermediate frequencies.

Peak displacements frequently correspond to the lower-frequency motional elements of an earthquake. However, they can occasionally be difficult to spot due to errors in signal processing that occur during the processing and integration of accelerograms. Because of this, peak displacement as a measure of ground motion is not as frequently utilised as peak acceleration or peak velocity.

The distribution of a ground motion's amplitude over different frequencies is represented by frequency content. Because the frequency content of an earthquake motion has a significant impact on its effects, characterization of the motion is incomplete without taking this into consideration. To calculate the ground motion that a structure is expected to experience during an earthquake, ground motion parameters are utilised together with seismic hazard maps. This knowledge is essential for constructing structures that are resistant to earthquakes and determining the likelihood that they will sustain damage or collapse.

1.4 Seismic Hazard Analysis

Although these phenomena can also be caused by human activity, a seismic hazard is frequently defined as a natural phenomenon (such as ground shaking, fault rupture, or soil liquefaction) caused by an earthquake. These impacts (such as those on dams, levees, buildings, lifelines, and power plants) might be severe and destructive or just annoying depending on the size of the earthquake, the distance a site is from the earthquake, local site features, and the reaction of the system of interest. Seismic hazard analysis frequently refers to the estimation of earthquake-induced ground motions with specific probabilities over time. In engineering practise, the term "seismic hazard" can also specifically refer to strong ground motions caused by earthquakes that could affect engineered structures. In this section, seismic source characterization, ground shaking, and the development of ground motions for engineering analyses are summarized.

There are two fundamental approaches—deterministic methods and probabilistic methods—for calculating the seismic ground motion risk in a particular area or at a particular location. Reiter (1990) describes these techniques in great detail. A Probabilistic Seismic Hazard Assessment (PSHA) creates "hazard curves" in terms of ground motion level and annually frequency of exceeding through the combination of seismic source zoning, earthquake recurrence, and ground motion attenuation.

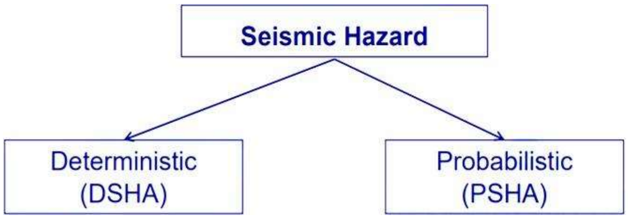


Figure 1.5 Types of seismic hazard

1.5 Probabilistic Seismic Hazard Analysis (PSHA)

The Probabilistic Seismic Hazard Analysis (PSHA) approach is used to calculate the probability that an earthquake would cause ground motion at a certain place and time. It is a statistical method that creates a model of earthquake incidence and ground shaking using data from earthquakes and other geology information.

The PSHA process involves several steps:

1. Determining probable earthquake sources involves locating and mapping active faults, seismic zones, and other sources of seismic activity in the area.

2. Creation of earthquake catalogues: This entails gathering information on previous quakes that have occurred in the area, such as their epicentre, magnitude, and focal depth.

3.The third step is the estimation of earthquake parameters, which entails examining the data from the earthquake catalogue to ascertain the maximum magnitude and frequency of earthquakes that might happen in the area.

4. Development of ground motion prediction equations (GMPEs): This involves developing mathematical models that gauge the potential for ground shaking depending on the strength of an earthquake, its distance from the epicentre, and other variables.

5. Development of hazard curves: Using earthquake data, GMPEs, and other information, hazard curves are created that depict the projected likelihood that ground shaking may surpass a certain level at a certain site during a specified period of time.

Overall, the PSHA approach offers crucial data for assessing seismic risk and coordinating disaster management. It may be used to influence a region's building rules, design standards, and emergency response strategies.

1.6 DSHA(Deterministic Seismic Hazard Assessment)

DSHA is a method to assess the seismic risk that is unique to each research site and is impacted by the sources that pose the most danger. Because earthquakes can occur at any time, DSHA fails to evaluate sources other than the biggest "controlling" source and does not take temporal factors into account. Ignoring these factors may occasionally reduce the conservatism of the hazard assessment when additional non-controlling sources present risks that are roughly comparable to the controlling sources or when the structure's design life exceeds the return time of the controlling source earthquake.

- Determining the origins of earthquakes.
- Determining the source-to-site separation for each source zone.
- Choosing the earthquake that is most likely to cause the greatest amount of shaking.
- The ground motion brought on by the controlling earthquake is taken into consideration in the formal determination of the site's risk.

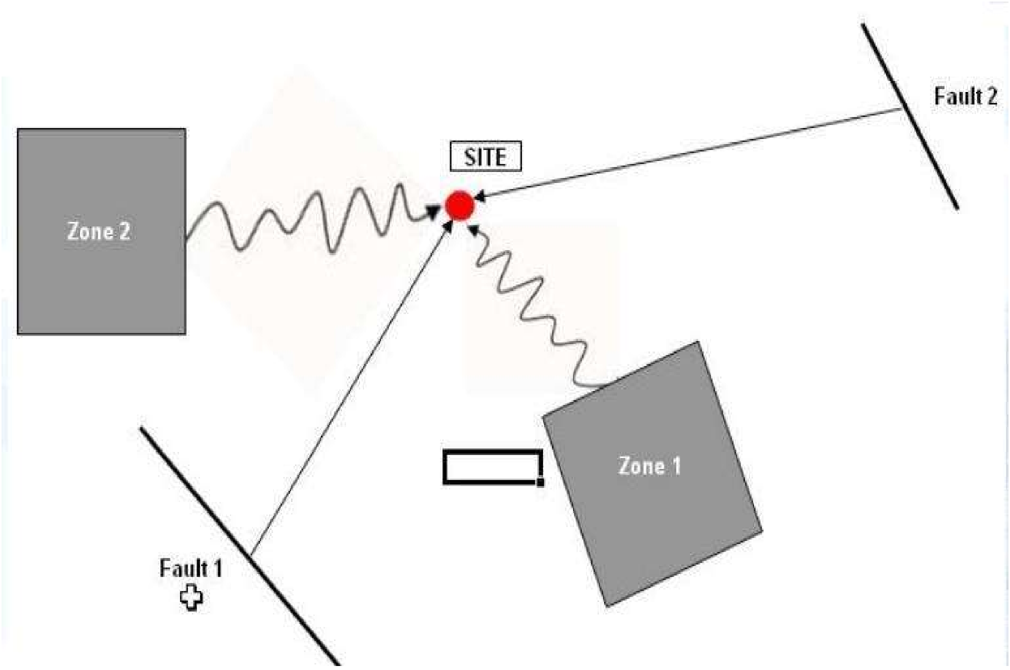


Figure 1.6 DSHA Illustrations

Basic steps for Deterministic seismic hazard analysis –

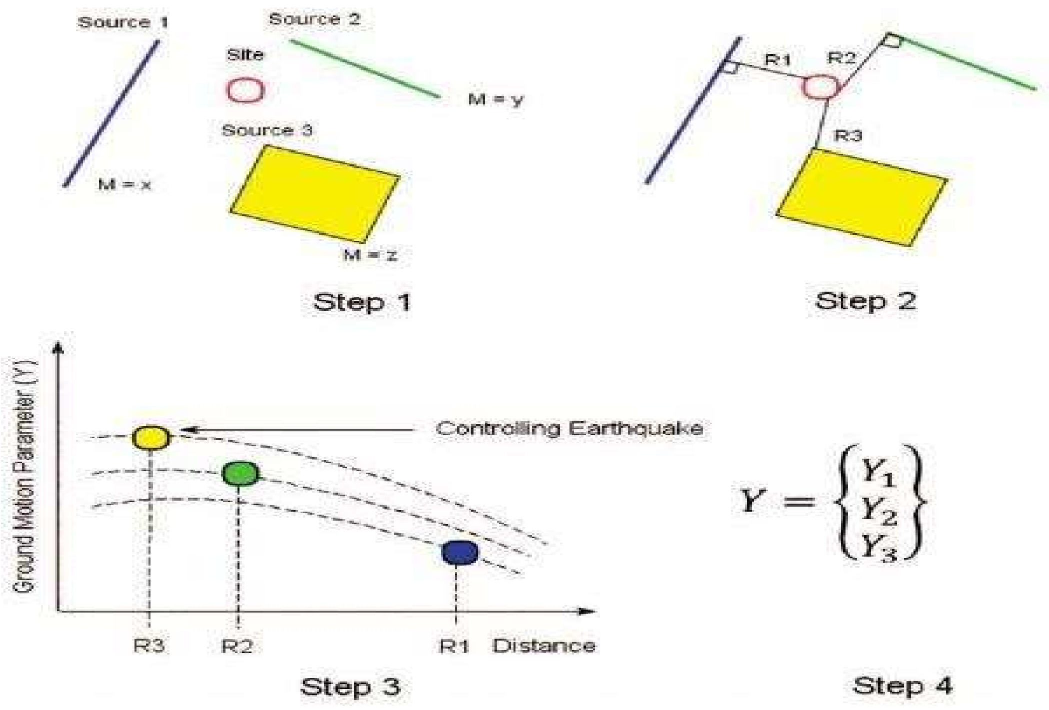


Figure 1.7 DSHA basic steps

1.7 Deterministic Seismic Hazard Assessment For The Region

These procedures can be utilised for carrying out a deterministic seismic hazard assessment for the Himachal Pradesh region:

1. Finding probably seismogenic sources in the area, such as active faults, subduction zones, and seismic zones, is the first step.

2. Create an earthquake database: For the area, an in-depth earthquake catalogue that takes into account historical, instrumental, and archaeological information is needed.

3. Calculate earthquake parameters: The third stage is to calculate earthquake parameters for each seismogenic source, such as magnitude, depth, and frequency of recurrence. Numerous methods, including Monte Carlo simulations and maximum likelihood estimation, can be used to accomplish this.

4. Create ground motion prediction equations: For a certain seismogenic source and site characteristics, ground motion prediction equations are generated to calculate the magnitude of ground shaking that may be expected during an earthquake.

5. Create risk curves: By integrating the equations for predicting ground motion with estimated earthquake characteristics and site-specific circumstances, hazard curves are created. These curves show the likelihood that there will be more than a specified amount of ground shaking at a specific location for a specific amount of time.

6. Interpret the findings: The hazard curves may be used to pinpoint seismically dangerous regions and the degree of ground trembling to be anticipated for various seismic sources and site circumstances.

A important method for determining the probable effects of earthquakes on vital infrastructure and creating appropriate building regulations and design standards is the deterministic seismic hazard assessment. It should be highlighted that deterministic seismic hazard assessment has limits since it does not account for all situations that might result in earthquakes and the probability associated with each one. As a result, it tends to be accepted that probabilistic seismic hazard assessment is a more thorough and reliable approach for determining seismic danger.

The goal of unsuccessful empirical research for the past 130 years has been "earthquake prediction," which is generally defined as the issuance of a science-based warning of an approaching destructive earthquake with sufficient accuracy and reliability to support actions like evacuations. Therefore, using earthquake prediction to reduce earthquake risks is not presently a viable option.

PSHA's objective is to calculate the likelihood that certain ground-motion levels will be exceeded at a spot (or a map of sites) given all potential earthquakes. The numerical/analytical method to PSHA was first formally established by Cornell (1968). PSHA was first discussed by C. Allin Cornell in "Engineering Seismic Risk Analysis" in 1968.

In order to plan for future earthquakes, PSHA determines the mean yearly rate of exceeding or potentially exceeding ground-motion parameters in a certain location, such as peak spectral acceleration (PSA) or peak ground acceleration (PGA). Despite the fact that PSHA's data is extremely valuable, the inherent uncertainties might result in incorrect interpretations. For both new and existing installations, these risks must be recognised and handled as part of the PSHA process. The PSHA approach is well known and recognised as a more accurate seismic hazard estimate globally. The procedure has undergone several updates since it began. Since the process' commencement, various updates have been made.

When faults nearby a site are not obvious, it can be difficult to identify the worst-case scenario at that location, so the seismic source is defined as an area source that may trigger earthquakes anywhere.

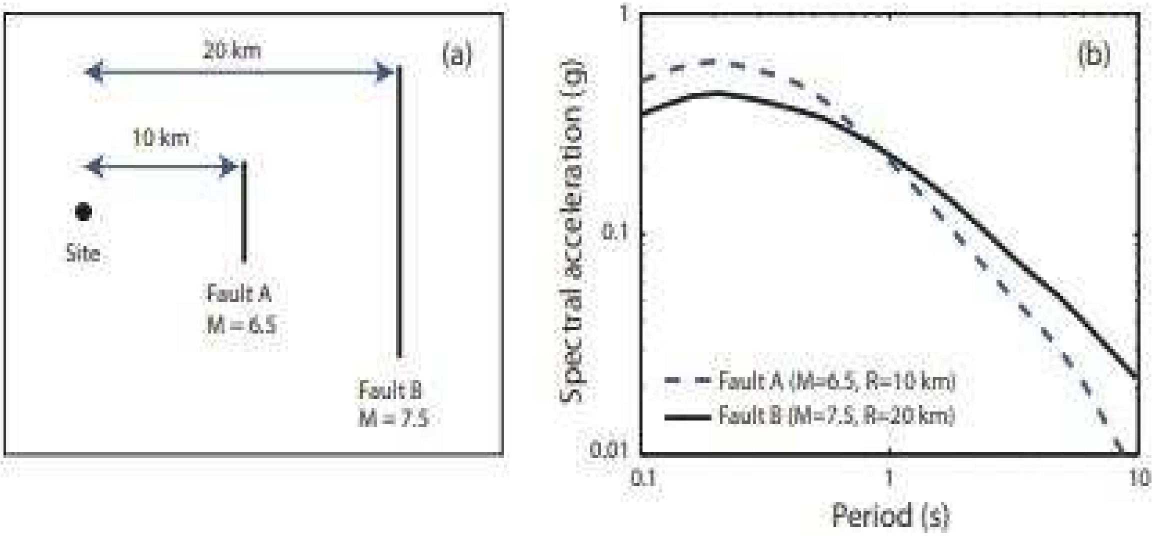


Figure 1.8 (a) A view of a place with two neighbouring earthquake-producing sources. (b) Predicted median response spectra from the two seismic occurrences, demonstrating that the event yielding the highest reaction spectra varies based on the time period of interest.

The worst-case scenario in this illustration must be the biggest catastrophe that may possibly happen just below the site of interest (i.e., at a distance of 0 km). Regardless matter how rarely it occurs, this is unquestionably the greatest event.

As mentioned in the section above, choosing the "worst-case" earthquake might be difficult and subjective, but choosing the worst-case ground motion intensity related to that earthquake can be significantly more challenging.

In order to calculate the level of ground motion intensity that will be exceeded at a tolerably extremely low rate, we will utilise PSHA to analyse all potential earthquake occurrences and simultaneous ground motions, as well as their related probability of occurrence.

At its most basic level, PSHA consists of five phases.

- Locate any possible earthquake sources that might result in dangerous ground vibrations.

- Ascertain the earthquake magnitude distribution.

- Describe the distribution of earthquake source-to-site distances that are likely to occur.

- Make predictions about the distribution of ground motion intensity based on the size and location of the earthquake and take other factors into account.

- Combine uncertainty in earthquake size, location, and movement of the ground intensity using the total probability theory.

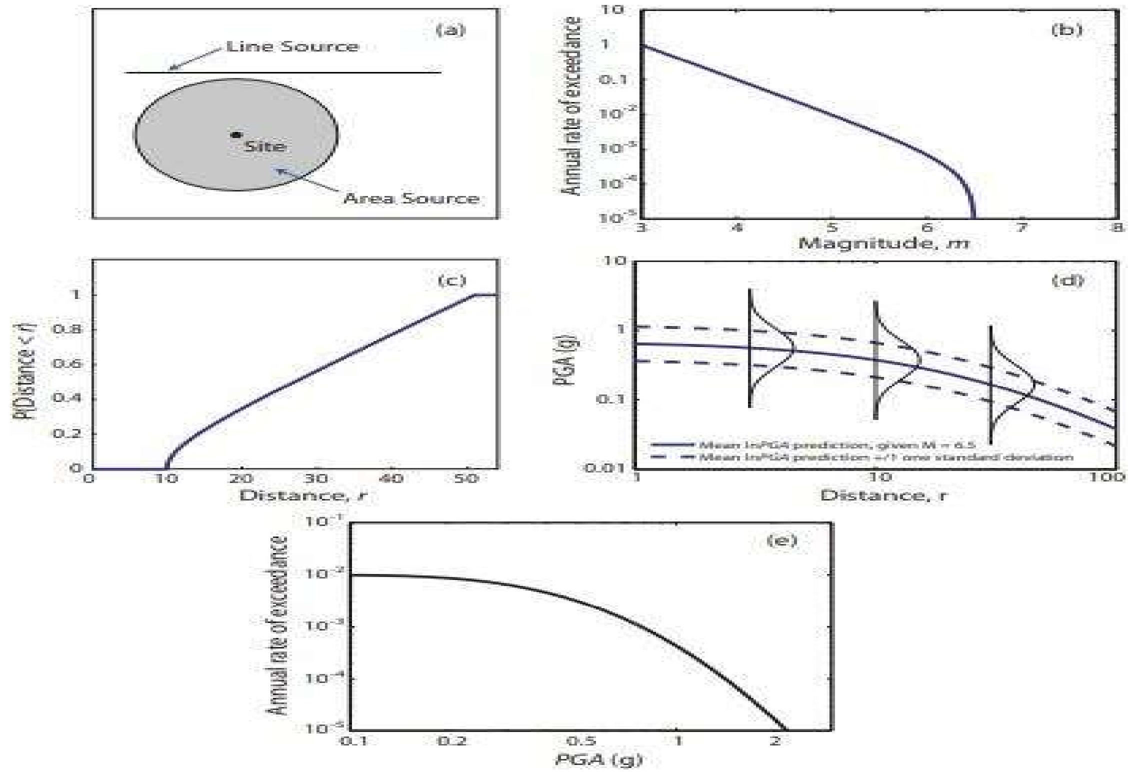


Figure 1.9 Illustration of the steps involved in a PSHA of site.

(a) Determine the origins of earthquakes.

(b) Describe the magnitude distribution of earthquakes from each source.

(c) Define the source-to-site distance distribution from each source.

(d) Forecast the intensity distribution of ground motion.

(e) Integrate data from sections a-d to calculate the yearly rate of exceeding a certain ground motion intensity.

Chapter 2

LITERATURE REVIEW

2.1 General

This chapter includes critical analysis of various articles, books and journals about Probabilistic seismic hazard assessment. Different literature has been evaluated, which helped us in understanding different methods and different site conditions used for a detection of SHA. In this chapter we could also identify the research gaps. Brief summary of a few other research papers is also provided below.

2.2 Various Seismic Hazard Studies

2.1.1 Baker, Jack W. (2015)

They conducted a general investigation into earthquake and seismic activities in their report. They conclude that earthquakes are a very common phenomena considered to be a serious problem since it is ubiquitous in the natural environment, has detrimental impacts on structure, and environment. They were mostly based on subjective and deterministic judgments that delineated zones with varied levels of seismic damage.

2.1.2. DAS, S., GUPTA, I.D. and GUPTA, V.K.(2006)

Seismic hazard analysis is significant in earthquake-resistant structure design because it provides a logical value for input hazard parameters such as peak ground acceleration PGAa or response spectrum amplitudes at different natural periods. (PGA) has long been a popular hazard metric, however it has been found to be very weakly related to ground motion harm potential. As a result, it is being phased out progressively in favor of pseudo-spectral velocity PSV or pseudo-spectral acceleration PSA, which are seen to be more thorough in conveying danger levels. In this study, a spectral attenuation model particular to Northeast India was used, together with 261 accelerograms collected from six seismic events around the region. These statistics are obtained from the focal point, IIT Roorkee.

2.1.3. Jaiswal KS and Sinha R (2007)

The study proposes assessments of the currently used methodologies for detecting the earthquake source and its distance, with an emphasis on the most practical techniques and approaches. To address these issues, a probabilistic seismic hazard analysis was conducted in this work, and seismic hazard maps based on PSA amplitudes at various natural times were created.

2.1.4. Sinha, R., Sarkar, R. (2020)

In this work, bedrock-level hazard maps for the city are created by probabilistic seismic hazard analysis (PSHA). The primary goal of this inquiry is to conduct a thorough PSHA at the foundational level for Dhanbad City. They also discuss a critical study on the impact of earthquakes. As a result, this study gives a thorough grasp of various strategies for detecting and considering the different seismic waves as well as their related Difficulties. Final results help us to figure out a seismic hazard curve of the Dhanbad city which recommended earthquake-proof designs for the upcoming times.

2.1.5. C.K, Mohanty, W.K & Ranjan, P. (2020)

The closeness of nearby large Himalayan earthquakes and the heavy alluvium deposits left by the Ganga River system make the Indo-Gangetic plains the region's most seismically sensitive. Quantifying the earthquake risk in the Indo-Gangetic plains is necessary given the rise in urbanization on this plain. The following list contains the main findings of the study. The results of the probabilistic seismic hazard analysis deliver the essential input for further seismic probabilistic safety analysis of nuclear power plants on Indo-Gangetic plains by providing important information about spectral frequency and level of ground motion at various probabilities in terms of seismic hazard curves and uniform hazard spectra.

2.1.6. Wangg, T., Liu, Jm., Shi, Js.etal. (2020).

We provide a probabilistic technique in this case study that is based on the probabilistic seismic hazard analysis method. As an example, the Tianshui seismic zone on the northeastern Tibetan Plateau (105°00′-106°00′ E, 34°20′-34°40′ N) was employed. In this study the Newmark's displacement model is used. The study area can provide us with guidelines for land use planning and hazardous and disaster management in the region, as well as valuable references for landslides hazard management and infrastructure designs in mountainous seismic zones.

A significant flaw in the majority of research articles and reports on probabilistic seismic hazard analysis relates to the likelihood of earthquakes whose magnitudes are not covered by the data (Speidel, 1996). In other words, PSHA has an issue since it is entirely dependent on the pattern of previous earthquakes because it uses a frequency-magnitude model. Because it is impossible to predict the probability of an event that has not yet occurred, PSHA cannot be justified statistically. So, we cannot entirely rely on the data that is obtained. The Indian Himalayan area, particularly the Western Himalayas, which are located in the seismic zone 4-designated Himachal region, has received relatively little study and investigation. This research will assist address the earthquake-related issue and may offer a way.

2.1.7. Tariq et al. (2020)

focused on the seismic hazard assessment of the Kashmir valley region, which is located near the study region. The study used probabilistic seismic hazard analysis and developed a ground motion prediction equation for the region. The results of the study showed a high seismic hazard in the region, with a high probability of ground shaking exceeding the design levels for various engineering structures.

2.1.8. Kundu et al. (2019)

focused on the seismic hazard assessment of the Sikkim region, which is located near the study region. The study used a probabilistic seismic hazard analysis and developed a ground motion prediction equation for the region. The results of the study showed a high seismic hazard in the region, with the northern part of the state having the highest hazard.

2.1.9. Bilham et al. (2015)

focused on the seismic hazard of the Himalayan region and identified several seismogenic sources in the region. The study used historical earthquake data and satellite geodetic data to estimate the earthquake parameters for each seismogenic source. The results of the study showed a high seismic hazard in the region, with a high probability of large earthquakes occurring in the future.

2.1.10. Kumar et al. (2021)

focused on the probabilistic seismic hazard assessment of Himachal Pradesh. The study used the Cornell-McGuire approach and identified the potential seismogenic sources and their associated earthquake parameters. The results of the study showed a high seismic hazard in the region, with the southern part of the state having the highest hazard.

2.3 Summary of the Literature Review

The Himalayan Mountain range, formed by the collision of two continents, is a seismically active area classified on the India hazard zonation map as seismic zones IV and V. The Indian plate continues to move north, causing tension at the plate boundary to be released as massive and powerful earthquakes. With the region's urbanisation and increased construction, it is critical to prioritise seismic hazard assessment. This research presents in-depth research on probabilistic seismic hazard analysis for mountainous regions in the Western Himalayas. By estimating seismicity parameters for each of the source zones, which are input variables into seismic hazard estimation for a region, the study accounts for local variation in tectonics and seismicity characteristics. The findings of this study can be applied to risk assessment and disaster mitigation studies, as well as quantitatively assessing earthquake risk in India and comparing it to other countries. The findings can also be used to develop risk-informed building design guidelines, to plan more carefully for land use, to optimise earthquake insurance pricing, and to improve general earthquake risk awareness and preparedness. Ultimately, this study is critical because it provides valuable insights into earthquake risk in the Western Himalayas and can inform disaster mitigation and risk reduction policy and decision-making.

2.4 Objectives

1. In order to better understand the risk of earthquakes in this region and create efficient measures for disaster mitigation, a concentrated study on seismic hazard assessment in the Western Himalayas region, with a focus on mountainous terrain, is needed.

2. To improve overall earthquake risk awareness and readiness in the area by using the study's findings to establish standards for building design that take risk into account and may be utilised to reduce building damage in the event of an earthquake.

3. To uncover parallels and contrasts between the study's findings with seismic hazard evaluations in other areas and nations in order to better understand earthquake risk internationally

CHAPTER 3

METHODOLOGY

3.1 General

In the seismically active northwest Himalayas is the state of Himachal Pradesh. The large number of large earthquakes that have occurred in this region as well as the Himalayan orogeny are to blame for the high seismic activity. The identification of potential seismogenic sources, the compilation of the earthquake catalogue, the estimation of earthquake parameters, the development of ground motion prediction equations, and the generation of hazard curves were all steps in the probabilistic seismic hazard assessment in Himachal Pradesh. Each stage is described in further detail below:

1. Identifying prospective Seismogenic Sources:

The methodology's first stage was finding prospective seismogenic sources in the study area. The existing geological and seismological data, including fault maps, seismicity maps, and geodetic data, were reviewed in order to do this. Active faults or background seismicity zones were used to classify the discovered seismogenic sources.

2. Compilation of the Earthquake Catalogue:

The following phase involved creating a thorough earthquake catalogue for the study area. The catalogue contained all the information that was known about previous and recent earthquakes that took place within and close to the research area. The catalogue was then implemented to calculate earthquake magnitudes and recurrence rates.

3. Estimation of Earthquake Parameters:

The maximum magnitude, b-value, and Gutenberg-Richter (G-R) parameters of earthquakes were all calculated using the earthquake catalogue. The frequency-magnitude distribution of earthquakes in the study region has been calculated using the G-R parameters.

4. Developing Equations for Predicting Ground Motion:

Using the strong motion data that were accessible from the research location, ground motion prediction equations (GMPEs) were devised. The GMPEs were created to account for various seismic source types and separations.

5. Producing Hazard Curves:

The final phase involved creating hazard curves applying the generated GMPEs and earthquake recurrence rates for various return periods. The possibility of excessive ground motion in the research zone was represented by the hazard curves.

The Cornell-McGuire approach, which is frequently employed in probabilistic seismic hazard assessments, served as a basis for the methodology used in this work. The methodology is a thorough and organised approach that enables the inclusion of different uncertainties in the study. It offers a reliable framework for calculating seismic threat in mountainous areas with complicated tectonic settings and geological features, such as Himachal Pradesh.

3.2 PSHA Methodology

An alternative definition of the PSHA is as a four-stage process, with each step having certain resemblances to the phases of the DSHA method.

Step 1

Except for the requirement to define the probability distribution of likely rupture locations inside the source, the first phase, identification and description of earthquake sources, is the same as the first step of the DSHA. The majority of the time, each source zone is given a uniform probability distribution, meaning that earthquakes have an equal chance of occur wherever inside the source zone. The relevant probability distribution of the source-to-site distance is then produced by combining these distributions with the source geometry. The DSHA, on the other hand, implicitly presupposes that the chance of occurrence is one at the places inside each source zone that are nearest to the site and zero elsewhere.

Step 2

Thus, it is essential to describe the seismicity or temporal distribution of earthquake recurrence. The seismicity of each source zone is explained by a recurrence relationship, which displays the typical rate at which an earthquake of a given size will be surpassed. Although the greatest magnitude earthquake may be possible due to the recurrence relationship, it fails to concentrate attention on just one earthquake, as DSHAs usually do.

Step 3

Applying predictive relationships is necessary to determine the ground motion at the site due to earthquakes of every imaginable magnitude occurring at every imaginable location in every source zone. The level of ambiguity around the predicted relationship is another factor taken seriously by a PSHA.

Step 4

Adding the uncertainties in the earthquake location, earthquake magnitude, and ground motion parameter predicted outcomes in a calculation of the likelihood that the ground motion parameter will be exceeded over a particular period of time. A PSHA must properly take into account the issues of source characterization, ground motion parameter prediction, and the physics of the probability computations.

Simply said, there are five phases for PSHA.

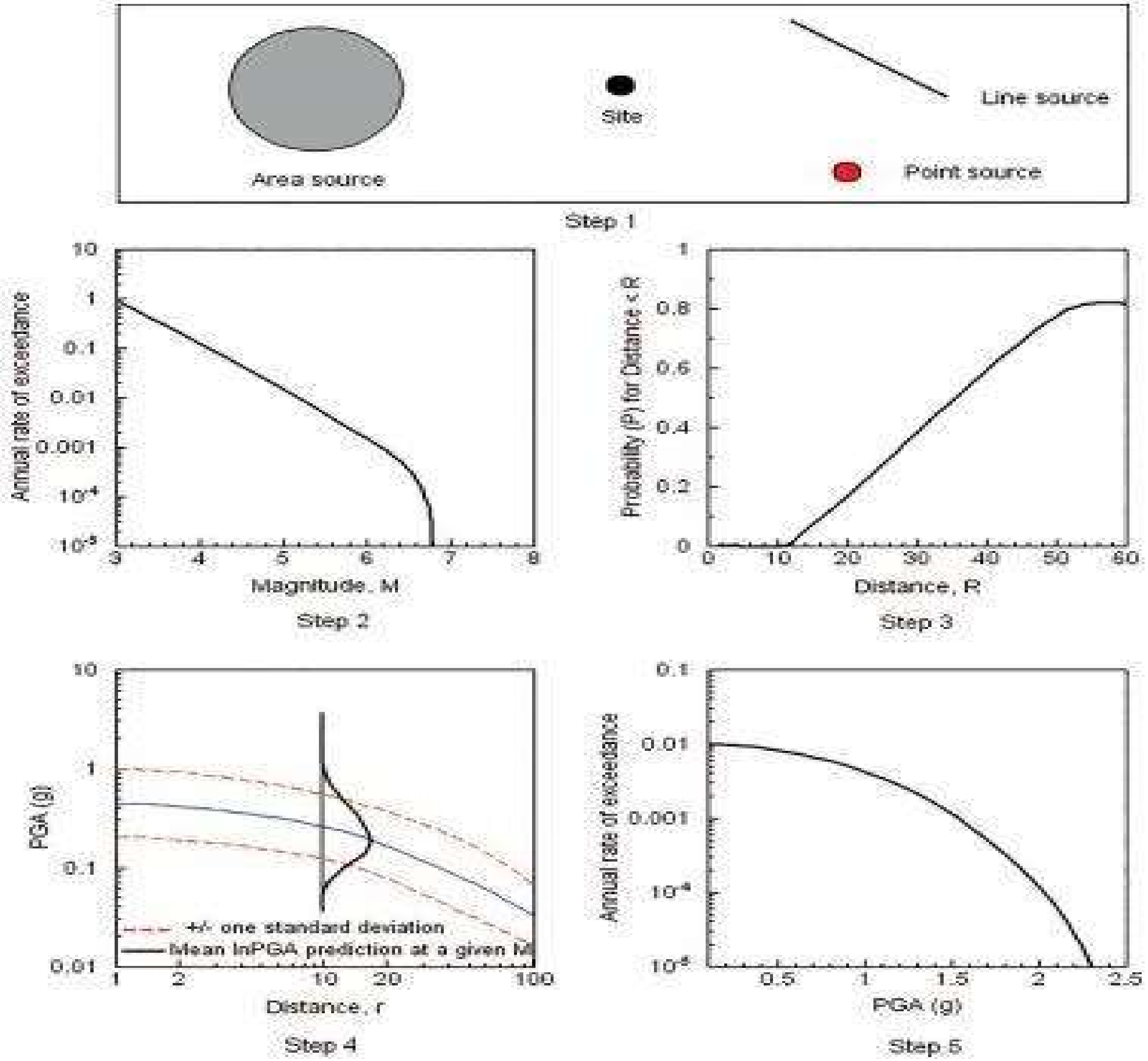
1. Determining and characterising the tectonic sources that may produce dangerous seismic waves.

2. Determining the lengths of time between earthquakes in a region of different magnitudes.

3. Determining source-to-site distances in relation to probable seismic events and distributing them.

4. For the size and distance of a specific earthquake, the distribution of ground motion is usually referred to as PGA.

5. To integrate uncertainty in several kinds of earthquake ground motion parameters, the total probability theory is applied.



Step 1

Step 2

Step 3

Step 4

Step 5

Figure 3.1 Steps involved in PSHA.

3.3 Study Region

Himachal Pradesh, in northern India and a region of the Himalayas, has experienced numerous moderate-to-large quakes, most notably the powerful Kangra earthquake of 1905 (Ms = 8.6, Mw = 7.8). The seismic zoning map of India places a sizable section of the state's land in Zone IV.

The research area's centre is located in Solan-Shimla at the coordinates 31.0079° N and 77.0881° E. The area around the plant that is of importance for seismic hazard evaluations has a maximum radial distance of 300 km. The Northern Western Himalayas, which are in seismic zone IV and are prone to earthquakes, are included in the research area.

The Shivaliks, the Lesser Himalayas, and the Greater Himalayas are the three mountain ranges that constitute up the Himalayan geology series.

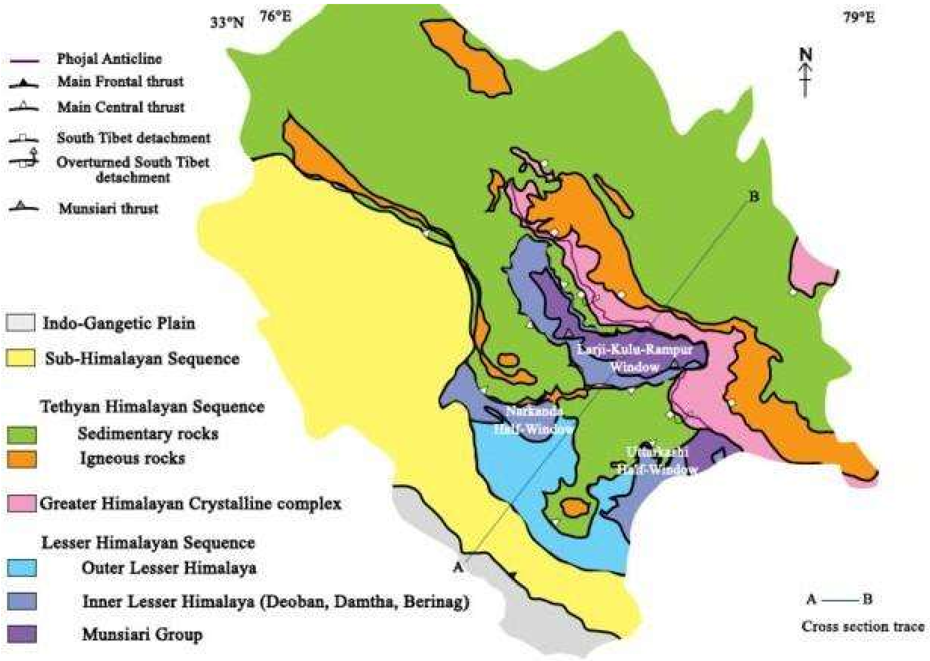


Figure 3.2 Simplified geological map of Himachal Pradesh

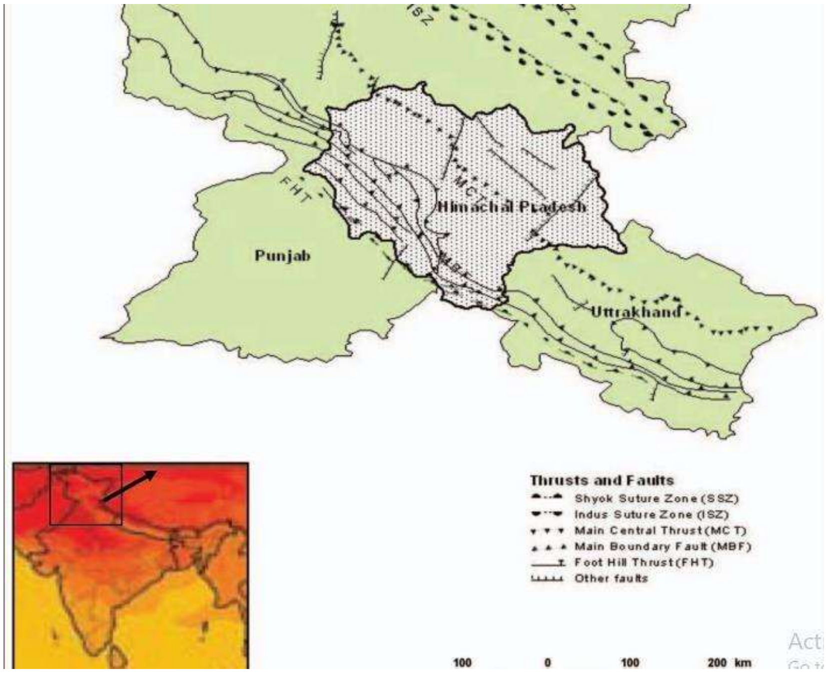


Figure 3.3 Study area and major lineaments: north-western India

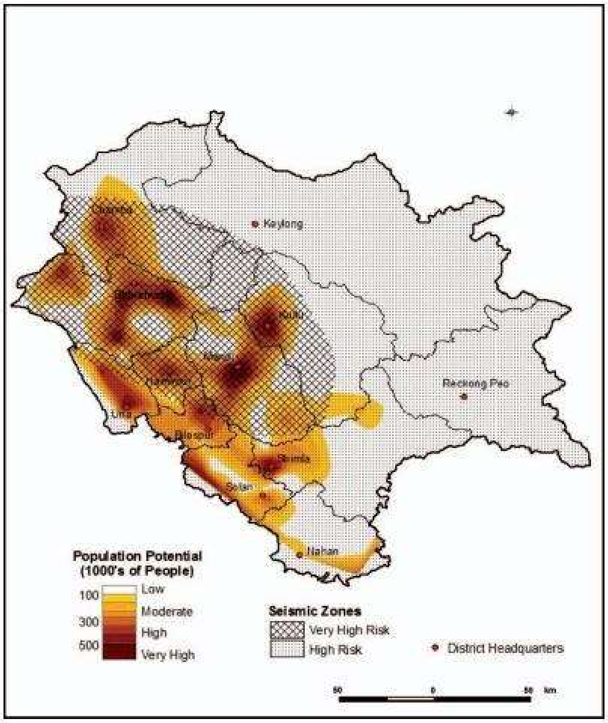


Figure 3.4 Himachal Pradesh: population potential and seismic risk zones

Table 3.1 District-wise area under seismic zones IV and V

S.No	District	Area under seismic Zone V (%)	Area under Seismic Zone IV (%)
1.	Shimla 00.38 99.62	00.38	99.62
2.	Solan	01.06	98.94
3.	Himachal Pradesh	32.02	67.98

3.4Geology and Seismotectonic

The zone area is an important input for PSHA, and seismogenic source zones and associated seismic features are identified and delineated using knowledge about the region's tectonics and seismicity. Himachal Pradesh and its neighboring territories are geologically and tectonically separated by the Himalayan orogenic belt and the Indo-Gangetic Plains. The Himalayan orogenic belt is responsible for the main geotectonic units and seismic characteristics seen in the study region.

The Shivalik’s, Lesser Himalayas, and Greater Himalayas are the three geological divisions of the Himalayas. The sub-Himalayan sedimentary rocks known as the Shivaliks represent the change from the Himalayas to the Indo-Gangetic plains. The Main Frontal Thrust (MFT) divides them to the south. According to DeCelles et al. (1998), this rock collection is from the middle Miocene to the Pliocene. The Lesser Himalayas make up the majority of the Himalayan region in our study area.

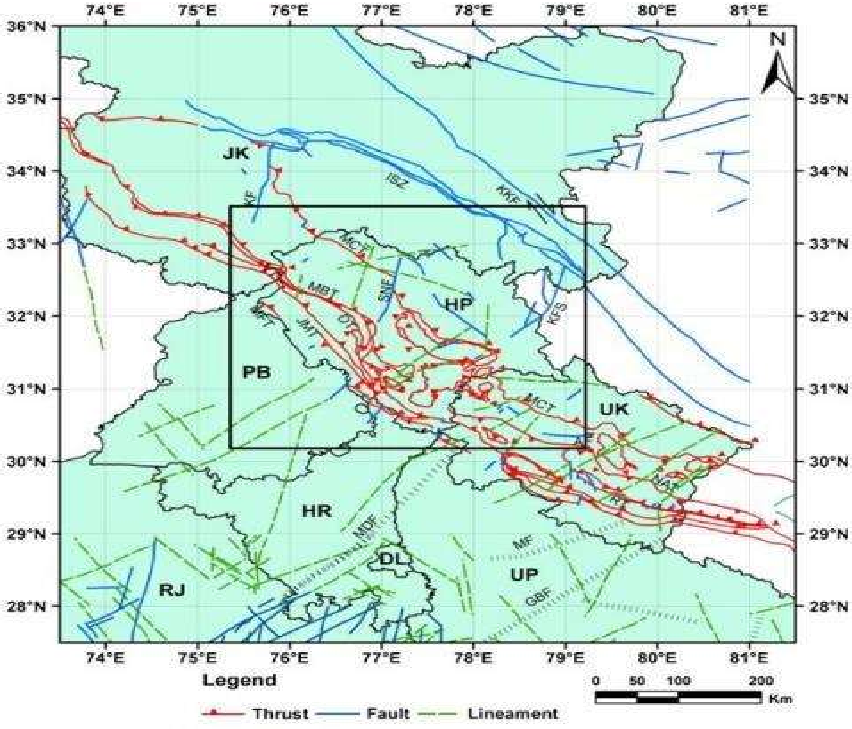


Figure 3.5 Tectonic features present in and around Himachal Pradesh

The following tectonic features can be found in and around Himachal Pradesh:

1.The Main Himalayan Thrust (MHT), a significant tectonic structure in the area, marks the intersection of the Indian and Eurasian tectonic plates. The Himalayas' continuing uplift and deformation are caused by the MHT.

2.The Lesser Himalayan Sequence (LHS) is a group of rocks made up primarily of metamorphic rocks such quartzite, schist, and gneiss. The immense pressure and heat produced by the collision of the Indian and Eurasian plates is what caused these rocks to develop.

3.The LHS is divided from the subordinate sedimentary strata of the Sub-Himalayan Belt by the Shali Thrust, a significant fault.

4. The Dhauladhar Thrust is an essential fault that separates the lower Himalayan rocks from the LHS.

5. The Himalayan Frontal Thrust (HFT): The Indo-Gangetic Plains and the Himalayas are separated by this surface expression of the MHT.

6. The Main Boundary Thrust (MBT): This significant fault divides the younger rocks of the Lesser Himalayan Sequence from the newer rocks of the Siwalik Group, which were deposited during the uplift of the Himalayas.

7. The Kangra Thrust: This significant fault divides the rocks of the Siwalik Group from the river deposits that are located above them.

3.5 Earthquake Catalog

The Advanced National Seismic System (ANSS), the National Centre for Seismology (NCS), and the United States Geological Service (USGS) were some of the sources that were used to build the dataset for this investigation.

The location, date, and magnitude of historical earthquakes in a region are listed in an earthquake catalogue. A reliable, thorough, and uniform inventory is required to determine the seismicity characteristics of the area's faults. This kind of a catalogue is accessible from the NDMA.

Many different sources are frequently utilised to collect seismic data. These sources define magnitudes using words like moment (Mw), body wave (mb), surface wave (Ms), local (ML), duration (Md), etc.

Due to its incapacity to saturate, the Mw is frequently used. All of the magnitudes are converted to Mw using empirical relationships established through the labour of numerous experts.

Table 3.2 List of earthquakes of magnitude ≥ 7 within a 500 km radius of Himachal Pradesh

Date	Latitude	Longitude	Magnitude	Depth	Reference
1662	34	75	7.5	-	IMD
6 May 1668	25	68	7		IMD

1735	34	75	7.5	-	IMD
1751	31.30	80	7	-	
1778	34	75	7.7	-	IMD
1784	34	75	7.3	-	IMD
1803	34	75	7		IMD
26 Aug 1833	27.50	86.5	7.5		IMD
1 May 1852	27	88.3	7		Oldham (1883)
1 Jan 1863	33.50	75.5	7		IMD
23 May 1866	27	85	7		IMD
30 May 1884	33.50	75.5	7.3	-	IMD
5 Jul 1895	37.80	75.2	7		IMD
4 Apr 1905	32.30	76.25	8	-	IMD

26 Sep 1905	29	74	7.1	-	IMD
28 Aug 1916	30	81	7.5	35	ISC
15 Jan 1934	26.60	86.8	8.3	-	IMD
27 May 1936	28.40	83.3	7	-	IMD
19 Nov 1996	35.31	78.2	7	-	ISC
8 Oct 2005	34.49	73.14	7.6	10	IMD

3.6 Soil Region and Profile

Depending on the circumstances surrounding the location and accessible area, this seismic refraction profile was scanned along contours that were nearly parallel to the road. The area is bounded by the mountainous Solan-Shimla highway, seismic zone IV, and an area under study with a length of 40 metres.

Three layers of the subsurface have been inferred based on seismic refraction survey: loose soil at the top mixed with hill outwash, relatively compact strata made up of completely weathered rock, and relatively compact rock produced up of highly to moderately weathered siltstone.

The characteristics of the soil profile –

Unconsolidated loose soil and stones make up the uppermost layer, which has a seismic velocity of about 270 m/sec. The second layer is made up of severely worn siltstone with seismic velocities of around 1394 m/sec. A layer of moderately worn siltstone follows, with a seismic velocity of around 2800 m/s (Table 3.3) The depths of different categories as interpreted are provided in Table 3.4.

Table 3.3 The depths of different categories

Depth 3.0 m	unconsolidated loose soil mixed with boulders	Vp = 270m/s
Depth 22m	Highly weathered Siltstone	Vp = 1394m/s

Bed Rock	Moderately Weathered silt stone	Vp = 2800 m/s

Table 3.4 – Depth of strata along profile

DISTANCE (m)	SURFACE ELEVATION (m)	DEPTH TO THE TOPOF SECOND LAYER	DEPTH TO THE TOPOF THIRD LAYER
0.0	1678.0	0.4	4.2
4.0	1675.4	0.0	2.4
8.0	1675.6	0.9	3.3
12.0	1675.3	1.0	3.5
16.0	1675.9	1.6	4.6
20.0	1676.0	1.3	5.0
24.0	1677.5	1.6	6.4
28.0	1679.7	2.1	8.1
32.0	1681.0	2.1	8.7

36.0	1681.9	1.5	9.2
40.0	1683.2	1.3	10.4

Table 3.5 Districts with EQ Intensities Types

Sr.No.	**Name of District**	**MSK IX or more % area**	**MSK VIII % area**
1.	Kangra	98.6	1.4
2.	Mandi	97.4	2.6
3.	Hamirpur	90.9	9.1
4.	Chamba	63.2	36.8
5.	Kullu	53.1	46.9
6.	Una	37.0	63.0
7.	Bilaspur	25.3	74.7
8.	Solan	2.4	97.6
9.	Lahaul & Spiti	1.1	98.9
10.	Kinnaur	--	100
11.	Shimla	--	100
12.	Sirmour	--	100

3.7 Prediction of Future Earthquake in the Himalayas

The entire Himalayan region is extremely vulnerable to a future great or mega earthquake, claim Roger and Bilham. The strain building over time has greatly increased as a consequence of the locking of the Indian and Eurasian plates. Four large earthquakes with a Richter Magnitude > 8.0 occurred in a short period of 53 years between 1897 and 1950, including those in Shillong, India, in 1897 (8.0), Kangra, India, in 1905 (8.0), and Los Angeles, California, in 1950 (8.0).

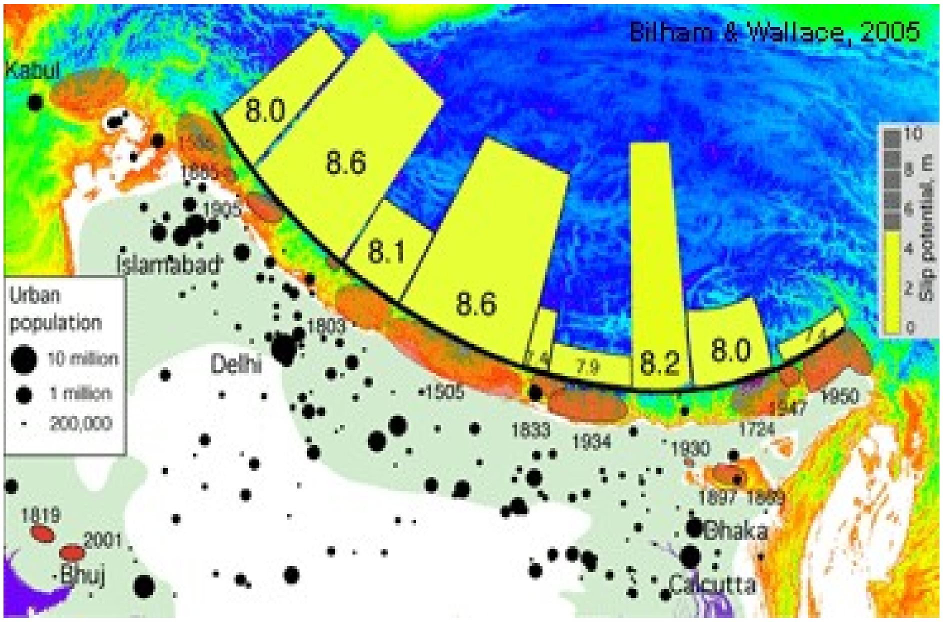
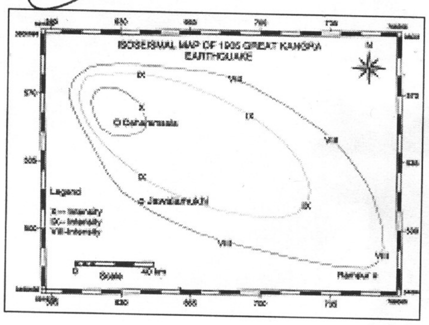


Figure 3.6 Prediction of future earthquake in the Himalayas

The model forecasts a magnitude 8 or 8.6 earthquake along the Kangra Chamba region. It is extremely concerning that an earthquake of this size took place in the area.

Fig.



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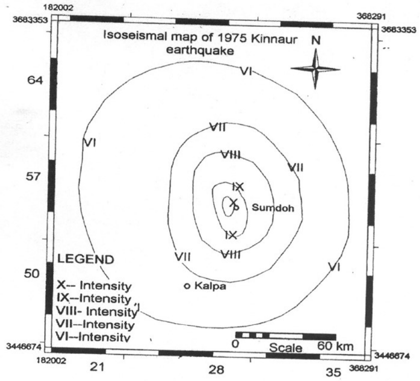

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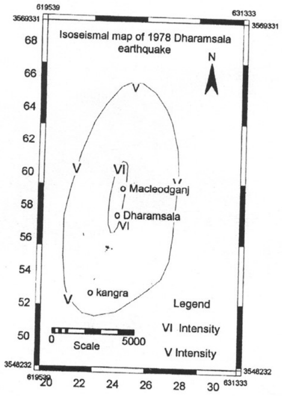

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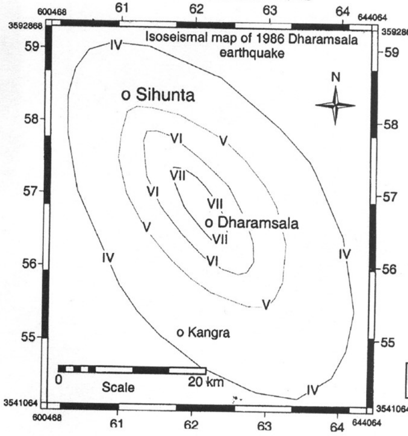
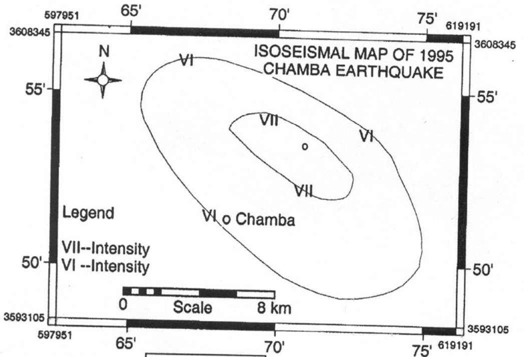


Fig.2d



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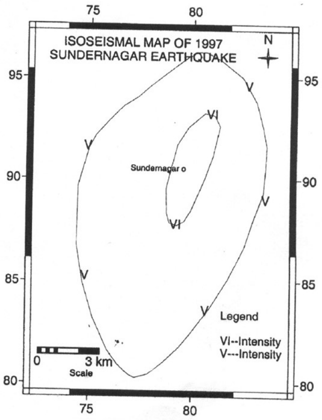

Fig.

Figure 3.7 Isoseismal Maps of Various earthquakes which rocked HP

3.8 Important Seismic Events of HP

The in-depth analytical examination of a few of the significant earthquake occurrences in Himachal Pradesh is provided in the paragraphs that follow. To analyse the state's seismic history and relate these occurrences to Dalhousie's current study area, detailed seismic analyses of the 1905 Kangra earthquake, 1975 Kinnaur-Lahaul earthquake, 1986 Dharamshala earthquake, 1995 Chamba earthquake, and 1997 Sunder Nagar earthquake have been provided. In order to get a conclusion for the current study, it was also necessary to assess how buildings behaved throughout these earthquakes. The Kangra earthquake of 1905 is chosen as the starting point for research since it is undeniably the largest and first major occurrence of enormous magnitude in the state's recorded seismic history.

1905 - Kangra (Himachal Pradesh), India, Mw 7.8

The 8.0-magnitude earthquake, which occurred at 004 50 m GMT or 06h 20 m IST, had its epicentre at 32.15 N, 76.15 E. It produced MM intensity X and higher in the epicentral region, claimed 20,000 lives, and affected an area of 4,16,000 sq. km. It turned out that a displacement along a low angle fault at a depth of 34 to 64 km (ASC) may have related to the earthquake.

One of the worst earthquakes in Indian history occurred on April 4, 1905, in the Dharamshala-Kangra region of Himachal Pradesh. 19,727 persons were murdered, according to the Punjab province administration of the time. Dharamshala, Kangra, and the surrounding villages and towns (ASC) provided the majority of the deaths (ASC).

On April 4th, 1905, at 6:19 a.m. I.S.T., the shock was felt and is estimated to have lasted at least two minutes. Kangra received the most severe damage (Middlemiss, 1910). The Golden Temple, the Municipal Dispensary, the Thana, and the Treasury buildings were all demolished. Only the Golden Temple's golden dome was still standing, sitting atop the rubble of the prior building. The Mission Church and the adjacent Devi Temple were both destroyed, and their debris merged with one another. earth. Another ruin was Kangra Fort. In and around Kangra (ASC), many landslides have erupted off the surrounding hills.

Following Kangra, Dharamshala and Palampur were the towns that suffered the greatest damage (Middlemiss, 1910). People trying to run outside in Dharamshala were hurled to the ground by the momentum, which was so intense. The 7th Gurkha Rifles from Kohima at the time were residing at the European Barracks, which had been entirely destroyed. Here, 363 troops were hurt and 272 soldiers were killed. The Armoury and other nearby structures suffered severe damage. However, several structures, like the Magazine, the Treasury, and the office and record room of Sadr Kanungo, remained intact. The earthquake was discovered to have distorted one of the cemetery's tombstones.

Dharamshala Civil Hill too sustained a great deal of building destruction. The earth was raised at Kotwali Bazaar and McLeodganj Bazaar. There were many cracks near the site of the jail, and one of them had a 10-foot slump along an ancient fracture. There were a large number of the victims. The strong shaking and the fact that the majority of people were indoors during the earthquake can be blamed for many of the fatalities. The majority of government officials were slain, and without anybody to assist or oversee rescue and relief efforts, this was a significant additional factor. It is thought that sounds calling for rescue may be heard from beneath wreckage for days at a time.

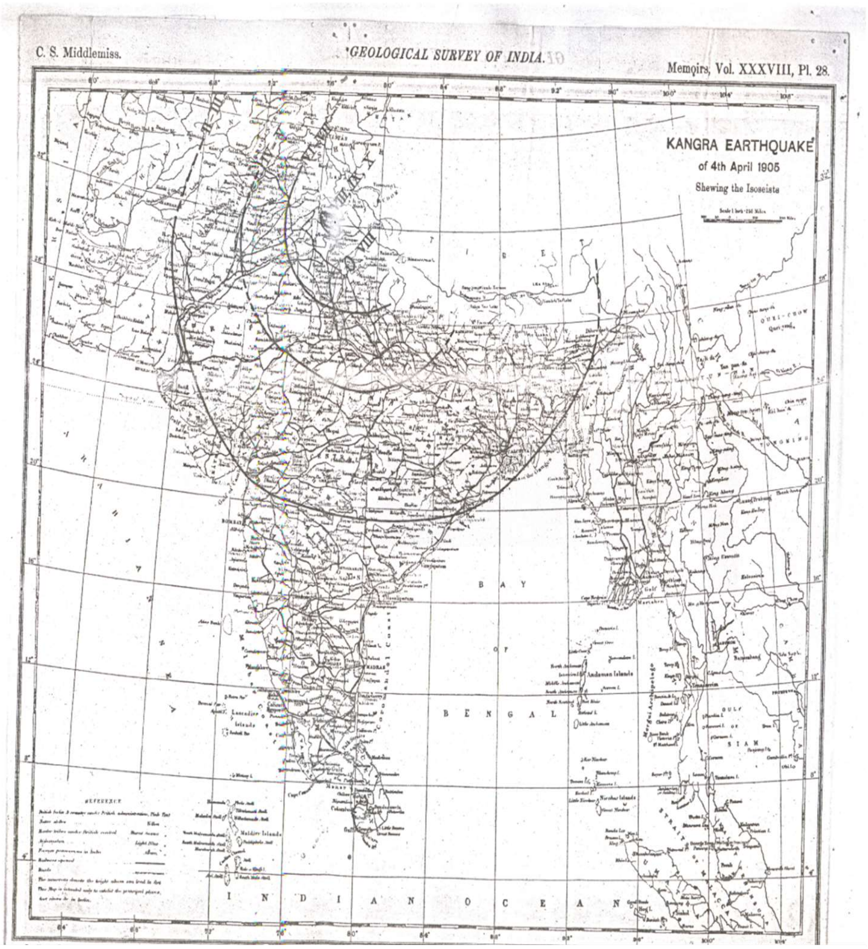

Figure 3.8 Isoseismal Map of 1905 Kangra earthquake

1975 - Kinnaur-Lahual & Spiti (Himachal Pradesh), India, Mw 6.7

On January 19, 1975, an enormous earthquake shook the Indo-China border. Its magnitude was 6.8, and portions of Kinnaur, Lahaul, and Spiti were devastated. There were tremors felt over much of northern India, including in New Delhi. The epicentre of the earthquake was either 26.7 kilometres southeast of Mt. Shilla (Himachal Pradesh) or 24.1 kilometres southwest of Chepzi (Xizang), China.

Northern India as a whole felt the effects of the earthquake. A large portion of Himachal Pradesh, as well as portions of Jammu & Kashmir, Punjab, and Uttaranchal, felt it heavily. Nearly 400 kilometres away in New Delhi, inhabitants of high-rise apartments reported hearing fans and other hung things oscillate, as well as hearing dishes rattle and furniture move.

A magnitude of 6.7 (Mw) is produced by empirical relationships between seismic moment (Mo) and surface wave magnitudes (Ms) for earthquakes in the Himalayan area. A moment magnitude of 6.4 is obtained using further relationships between seismic moment (Mo) and the body's wave magnitude (mb).

Dharamshala Earthquake: 26th April, 1986

This earthquake's M=5.7 epicentre was located at latitude 32.1 North and longitude 76.3 East, which is quite close to the location of the 1905 Kangra earthquake. The focal depth was shallow, at 10 kilometres, and the genesis time was 13 h 5 m 17 s, or IST. Fortunately, there were only approximately 6 fatalities because the earthquake did not continue very long, but a vast number of homes, including many government-owned structures in Dharamshala and neighbouring cities, were damaged.

Dharamshala Earthquake: 2021

The Himachal Pradesh province's Kangra district had a moderate earthquake on July 6, 2021, known as the Dharamshala earthquake. The epicentre of the 3.7-magnitude earthquake was situated 5 kilometres beneath the surface, 13 km east of Dharamshala.

Kangra, Dharamshala, and Palampur were among the Himachal Pradesh locations where the earthquake was felt. However, there were no reports of any serious infrastructure or building damage. People in the impacted districts fled their houses in fear throughout the brief duration of the earthquake.

The region's moving forward tectonic activity was what led to the earthquake that struck Dharamshala in 2021. Himachal Pradesh is situated in a seismically active area and has previously been the site of numerous significant earthquakes.

Immediate action was taken by the local government in Himachal Pradesh to evaluate the earthquake's damage and aid those who were harmed. To lessen the possibility of property damage or human casualties during future earthquakes, the state administration additionally emphasised the necessity for earthquake preparedness and mitigation measures.

Overall, the 2021 Dharamshala earthquake serves as a reminder of the area's seismic risks and emphasises the significance of Himachal Pradesh's earthquake preparedness and mitigation efforts.

The 24th March 1995 Chamba Earthquake

The Himalayan active seismic belt includes the Kangra-Chamba area. On April 4, 1905, the region was struck by a powerful earthquake which severely damaged the Bharmour area (Middlemiss 1910). Other destructive earthquakes that occurred in the Chamba area include those that occurred in 1945, 1947, and 1950, measuring 6.5, 6.0, and 5.5 respectively, and those that occurred in the Dharamshala region in 1968, 1978, and 1986, measuring 5.4, 5.0, and 5.7 respectively. At 17:22 IST on March 24, 1995, a moderate earthquake with a USGS magnitude of 4.9 mb hit the Chamba region and its surrounds. In Chamba Town and other southeasterly locations, the earthquake was felt intensely. Up to Bharmour was impacted to the northeast of Chamba, Tisa to the northwest, and Dalhousie and Pathankot to the southwest. Short-lived tremors inflicted minimal damage in an 8 km radius, with Pilure-Baraur sector villages experiencing the most.

The Sunder Nagar Earthquake (NW Himalayas) of 29TH July, 1997

A 5.0-magnitude (WIHG) earthquake rocked the Sundernagar area and its surrounds in the Mandi district of Himachal Pradesh around 23:30 (IST) on July 29, 1997. Within a 2-kilometer radius of the town of Sunder Nagar is the epicentral zone. About 1000 adobe homes were damaged by the main shock, which lasted a few seconds. The main shock, which was felt over a 300 sq. km. area, caused extensive wide cracks in adobe houses within the epicentral zone, with rare cases in other areas where hair cracks to 1mm width developed in concrete houses, the fall of plasters and the collapse of a few adobe houses within a 5 km. radius of Sundernagar

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Data of the Year 1981 with Earthquake Magnitude More Than 4

Table 4.1 Year 1981 Earthquake Having Magnitude More Than 4

Number	Magnitude	Latitude	Longitude	Location
1	4.0	32.35	76.37	Near Bara Kanda, District Chamba
2	4.5	32.43	76.00	Near Lohari, District Chamba
3	5.0	31°04'09.6"N	78°02'16.6"E	Nalpaya Thach (Distt. Kinnaur)
4	5.2	31°08'58.8"N	78°02'15.3"E	Barling (Kinnaur Distt.)

This data set contains earthquake events that occurred in India's northern region in 1981. There were four earthquakes ranging in magnitude from 4.0 to 5.2. The first earthquake, with a magnitude of 4.0, occurred on February 14 near Bara Kanda in District Chamba. The second earthquake, with a magnitude of 4.5, occurred on June 19 near Lohari in District Chamba. The third earthquake, with a magnitude of 5.0, occurred on June 13 near Nalpaya Thach in District Kinnaur. The fourth earthquake, with a magnitude of 5.2, occurred on May 28 near Barling in Kinnaur District. The last two earthquakes have latitude and longitude coordinates, while the first two only have approximate location names.

4.2 Data of the Year 1975 with Earthquake Magnitude More Than 4

Table 4.2 Year 1975 Earthquake Having Magnitude More Than 4

No.	Magnitude	Latitude	Longitude	Location
1	5.2	32°54'N	76°00'E	Near Bhujara, District Chamba
2	5.1	32°50'N	76°58'E	Near Jankar, Sumdo, Lahaul & Spiti
3	5.0	32°49'N	76°11'E	Near Chhajaut, District Chamba
4	6.7	31°05'36"N	78°03'48"E	District Kinnaur
5	5.1	32°33'36"N	78°05'30"E	Indo China Border
6	5.1	31°05'42"N	78°03'32"E	Near Chango (Kinnaur Distt.)
7	5.5	32°34'12"N	78°02'54"E	Near Kanum (Distt. Kinnaur)
8	5.3	32°05'24"N	76°00'00"E	Near Janu Pass (Chamba Distt.)
9	5.0	33°00'00"N	76°10'12"E	Near Sathrundi (Chamba Distt.)

The data presented here represents earthquakes that occurred in India in 1975. The information includes the date and magnitude of the earthquake, as well as the location's latitude and longitude. The earthquakes occurred in several districts of Himachal Pradesh, including Chamba, Lahaul and Spiti, and Kinnaur. On January 19, 1975, an earthquake with a magnitude of 6.7 struck the Kinnaur district. The magnitudes of the earthquakes ranged from 5.0 to 6.7, with a total of 9 earthquakes recorded in the data.

4.3 Data of the Year 1996 with Earthquake Magnitude More Than 4

Table 4.3 Year 1996 Earthquake Having Magnitude More Than 4

No.	Magnitude	Latitude	Longitude	Location
1	4.0	32°50'N	76°19'E	Near Kuntka Matha, District Chamba
2	4.2	32°42'N	76°29'E	Near East of Kagal Dhar, District Chamba
3	4.1	32°37'N	76°31'E	Near East of Dhan Kanda, DIstrict Chamba
4	4.6	32°49'N	76°22'E	Near Kala Ka Bhandar, District Chamba

Several earthquakes struck the Himachal Pradesh district of Chamba in 1996. The first earthquake, which occurred on May 9, had a magnitude of 4.0 and occurred near Kuntka Matha. The second earthquake, with a magnitude of 4.2, occurred on May 23 in the east of Kagal Dhar. On July 14, another earthquake with a magnitude of 4.1 struck near Dhan Kanda. Finally, on September 14, a 4.6 magnitude earthquake struck near Kala Ka Bhandar. All of these earthquakes had magnitudes ranging from 4.0 to 4.6 and occurred in the Himachal Pradesh district of Chamba.

4.4 Data of the Year 1976 with Earthquake Magnitude More Than 4

Table 4.4 Year 1976 Earthquake Having Magnitude More Than 4 or 4

No.	Magnitude	Latitude	Longitude	Location
1	5.3	32058’12”	7607’12”	Dunchili Gad (Chamba Distt.)
2	4.7	32 59	76 01	Along J&K Border
3	5.0	31014’24”	77001’48”	Near Chebri (Distt.Shimla)
4	4.5	32 43	76 30	Near Balthal Got, District Chamba
5	4.0	32 52	76 00	Near makkan, District Chamba
6	5.1	32026’24”	78021’00”	Near Raksham (Kinnaur Distt.)
7	5.3	32014’08”	78045’36”	Near Baspa origin (Kinnaur Distt.)

This data set contains information on seven earthquakes that struck northern India in 1976. Each earthquake's year, month, day, magnitude, latitude, longitude, and location are listed in the table. The magnitudes range between 4.0 and 5.3. The earthquakes occurred in the Himachal Pradesh districts of Chamba and Shimla, as well as in the Himachal Pradesh district of Kinnaur, which borders Jammu and Kashmir.

4.5 Data of the Year 1999 with Earthquake Magnitude More Than 4

Table 4.5 Year 1999 Earthquake Having Magnitude More Than 4 or 4

No.	Magnitude	Latitude	Longitude	Location
1	4.9	31 48 36	78 54 36	Near Miyang Lung, District Kinnaur
2	4.2	31 26 24	77 18 00	Near Mehog, District Mandi
3	4.9	31 48 36	78 54 36	Near Miyang Lung, District Kinnaur

No.	Magnitude	Latitude	Longitude	Location
4	4.1	31 22 48	77 17 24	Near Karsog, District Mandi

This data set contains information about earthquakes that occurred in various districts of Himachal Pradesh, India, in 1999. On May 30, 1999, a 4.9 magnitude earthquake struck near Miyang Lung in the Kinnaur district. On the same day, another earthquake of the same magnitude was recorded at the same location. On January 8, 1999, a 4.2 magnitude earthquake struck near Mehog in the Mandi district. On the same day, another 4.1 magnitude earthquake struck near Karsog in the same district. These earthquakes all occurred in Himachal Pradesh, India, and had magnitudes ranging from 4.1 to 4.9.

4.6 Data of the Year 2000 with Earthquake Magnitude More Than 4

Table 4.6 Year 2000 Earthquake Having Magnitude More Than 4 or 4

No.	Magnitude	Latitude	Longitude	Location
1	4.1	31 30 36	78 15 00	Near mehbar, District Kinnaur
2	4.5	32 01 48	78 18 00	Near Miyang Lung, District Kinnaur
3	4.0	30 55 12	75 39 00	Near Mehog, District Mandi
4	4.3	31 48 00	78 27 00	Near Nalpaya, District Kinnaur

This data set contains information on earthquakes that occurred in various parts of India in the year 2000. On April 28, 2000, a 4.1 magnitude earthquake struck near Mehbar in the Kinnaur district. The exact location of the earthquake on August 28, 2000, is unknown. On September 26, 2000, a 4.0 magnitude earthquake struck near 30°55'N 75°39'E. On June 17, 2000, a 4.3 magnitude earthquake struck near Nalpaya in the Kinnaur district.

CHAPTER 5

CONCLUSION

5.1 Conclusion of the Results Obtained

The results of PSHA studies in the Himalayan region point to a significant seismic hazard. The region is prone to earthquakes of varying magnitudes, including large and destructive events. The possibility of future earthquakes, including those of high magnitude, is still a concern. It should be noted that seismic hazard assessments are subject to uncertainties due to the complexity of earthquake processes and data limitations. Ongoing research and advances in seismology contribute to the refinement of PSHA models and the improvement of hazard estimates. As a result, it is critical for local authorities, engineers, and planners in the Himalayan region to consider the findings of PSHA studies and implement appropriate measures to mitigate the potential risks associated with earthquakes. To improve seismic resilience and ensure the safety of communities in the region, these measures may include building codes, land-use planning, and infrastructure design. Overall, the future of PSHA in the Himalayan region is dependent on advances in data collection, improved modeling techniques, and interdisciplinary collaborations. This will improve our understanding of seismic hazards and contribute to the development of effective mitigation strategies for the region's earthquake risks.

Seismic activity in the Himalayan Mountain range, particularly in the northwest mountainous region beneath Solan, Himachal Pradesh, is a major source of concern due to the potential for damage to people and infrastructure. Given the high seismic risk in the area, a probabilistic seismic hazard assessment was performed, which revealed that the region is vulnerable to ground shaking that exceeds the levels intended for various engineering constructions. As a result, it is critical to develop effective risk mitigation measures and emergency response plans, as well as to inform design standards and construction rules for future engineering structures designed to withstand seismic activity. The study gathered and analysed geological, seismological, and geotechnical data from a variety of sources in order to assess the potential ground motion at the study site. The Cornell-McGuire method was used to create hazard curves, calculate earthquake parameters, compile catalogues, identify potential seismogenic sources, and formulate ground motion prediction equations. The findings of the assessment emphasise the significance of disaster management planning and seismic risk mitigation in the area. The findings can help to inform disaster management policy and decision-making, as well as reduce the potential impact of future earthquakes on people and infrastructure. Overall, the study adds to our understanding of the seismic risk in the northwest mountainous area beneath Solan, Himachal Pradesh, which can be used to inform design standards, construction rules, disaster management planning, and emergency response plans in order to mitigate the impact of future earthquakes in the region.

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