Earthquake Risk Assessment of Buildings: Applicability of HAZUS in Dehradun, India

Brijesh Gulati January, 2006

Earthquake Risk Assessment of Buildings: Applicability of HAZUS in Dehradun, India

by

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Abstract

India is considered as one of the most disaster prone countries in the world. It has experienced several devastating earthquakes in the past resulting in a large number of deaths and severe property damage. The city of Dehradun is the interim capital of Uttaranchal in North India and has short-listed by United Nations Development Programme (UNDP) as one of the most earthquake prone city in the country. There is a direct relationship between the damage of civil structures such as buildings to the number of casualties. The frequent occurrence of damaging earthquakes clearly demonstrates the urgent need of study of earthquake risk assessment (ERA) methods of buildings to effectively reduce the impact of earthquake in the city. Although no precise risk evaluation model of earthquake risk and damage assessment can be developed till date in India. The devastating effect of an earthquake can be minimized to a great extent by adopting risk models developed in other countries.

The HAZUS is one of the ERA tools developed in the United States, which assesses the earthquake loss for the built environment and population in urban areas. The present study has been done with an aim to analyze the applicability of HAZUS model for the assessment of earthquake risk of buildings in India. By doing analysis of this model it will be easy to identify the shortcomings in the HAZUS approach for using it in India and possible modifications in terms of parameters to fill the gaps identified and to find the strength of using this model in India. The whole research was broadly divided into four major sections. The first section gave a review of risk assessment methods in India and in other countries. The second section dealt with the identification and generation of the dataset (seismic, ground motion, building response and damage functions) required for using HAZUS methodology in a study area. The third section dealt with the possible modifications required to use HAZUS based building classifications in a study area in India. The fourth section dealt with tested the HAZUS methodology for risk assessment of buildings in a study ward. This section also included the modifications needed in terms of parameters for the adoption of this methodology in study area.

The municipal ward of Dehradun is taken as the case study ward to test the HAZUS model in Indian condition. The Reinforced Masonry (RM) and Unreinforced Masonry (URM) model classes from HAZUS have been selected as most representative buildings in the study ward for ERA. The damage probability matrix has been developed for four model-building types by applying HAZUS methodology. Finally risk has been evaluated in terms of damage probability of each model building type for all four (slight, moderate, extensive and complete) damage states.

The research also concludes the modification required in HAZUS in defining the building inventory and simplifying the method of data collection in Indian context to adopt the HAZUS model more accurately in India.

Key words: earthquake, HAZUS, building vulnerability, seismic risk

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List of Abbreviations and Acronyms

BIS Bureau of Indian Standards
BIC Building Inventory Classification

BMTPC Building Materials and Technology Promotion Council

CBRI Central Building Research Institute

CGI Corrugated Galvanized Iron

DEQ-IIT Department of Earthquake Engineering - Indian Institute of Technology

DMC Dehradun Municipal Corporation
DRMP Disaster Risk Mitigation Programme

DCR Demand Capacity Ratio
ERA Earthquake Risk Assessment

FEMA Federal Emergency Management Agency

GIS Geographic Information System

GoI Government of India

GSDMA Gujarat State Disaster Management Agency

HAZUS Hazards United States

IDRN India Disaster Resource NetworkIIRS Indian Institute of Remote SensingIIT Indian Institute of TechnologyIMD India Meteorological Department

ITC International Institute For Geo-Information Science And Earth Observation

MS Mild Steel

MBT Main Boundary Thrust MCT Main Central Thrust

MDDA Mussorrie Dehradun Development Authority NIDM National Institute for Disaster Management

NBC National Building Code

NSET National Society for Earthquake Technology

NICEE National Information Center of Earthquake Engineering

PCC Plain Cement Concrete RB Reinforced Brick

RBC Reinforced Brick Concrete
RCC Reinforced Cement Concrete

RM Reinforced Masonry

SHRM Seismic Hazard and Risk Microzonation

RSP Rapid Screening Process ULB Urban Local Bodies

UNDP United Nations Development Programme

URM Unreinforced Masonry

1. Introduction

This chapter describes the context of the study, the relevance of this research, the main problem to be addressed, the aim of the study, the research objectives, research questions and expected output of this research. This chapter also contains an introduction of the study area, a general idea of research methodology and provides an overview of the structure of this report. It also addresses the impact of earthquake in urban areas in developing countries and the need to study the seismic risk assessment.

1.1. General Introduction

Developing countries are more vulnerable to hazards because of their increasing rate of development and urban growth. The lack of proper disaster management leads to increase in risk in more densely populated cities. Most of the growth in terms of civil structures and infrastructure will concentrate in the developing countries for the next few decades. These countries are already loaded with various urban problems like population growth, urban sprawl, building density and lack of financial strength. The risk is continuously increasing in these countries at an alarming rate.

The sole purpose of all mitigation processes in the world is to save human lives and property from the impact of natural disasters (Sokhi, 2000). It is impossible to live in a disaster free environment but it is possible to reduce the impact of disasters by proper risk management strategies. The pre-planned mitigation activities not only save the human lives but also reduce the potential effect of disasters. The proper disaster management strategy at initial planning level improve the overall functioning of the city and help us to face the ill effects of disaster. Earthquakes can create disasters of high magnitudes when they hit metropolitan areas of large population and infrastructure. Damage and loss estimation techniques are used to quantify potential, social and economic losses from earthquakes.

Earthquake damage and loss estimation is complex process. A loss estimation study for a major metropolitan area could take months to collect the underlying data and would require the participation of experts from several fields. Despite their complexity, loss estimation studies have proven to be a very useful tool for developing emergency preparedness plans and for promoting seismic risk mitigation (Agrawal, 2004). With the advancement of space technology and geographical information system (GIS), it is now possible to overcome the difficulties in evaluating the damage of urban infrastructure in a pre as well as post disastrous event. A high-resolution satellite image can significantly improve the efficiency and accessibility of loss estimation techniques. A remote sensing image can help in rapid damage data collection through direct observation of damage across a large geographic extent (Chiroiu et al., 2002). Traditionally, such damage information is collected through ground-based surveys. This process may take weeks or months following the event. During this period several ground changes will occur which might not provide accurate damage assessment. The database generated for buildings and infrastructure in GIS environment can effectively be utilized for preparing disaster management plan for any region. The quick and timely evaluation of the extent and severity of damage minimizes human suffering and streamlined rescue and relief operations. The advancement of

these tools and techniques helps the urban planners, emergency managers, risk managers and decision makers to understand the impact of earthquakes and incorporate the results into preparedness program and urban development plans.

Various steps have been taken by the Indian Government in the last few years to mitigate the urban earthquake losses. A number of projects have been initiated under a national disaster scheme to reduce earthquake loss in various urban cities of India (NIDM, 2004). Examples are the National Risk Mitigation Project (NRMP), Accelerated Urban Earthquake Vulnerability Reduction Programme (AUEVRP), National Programme for Capacity Buildings (NPCB), Development and Revision of Codes (DRC), Review of building bye laws and their adoption and National Core Group for Earthquake Risk Mitigation (NCGERM). The various government and non-government agencies involved in this area are National Disaster Management Division (NIDM, 2004), Indian Meteorological Department (IMD), Bureau of Indian Standards (BIS), Central Board of Road Institute (CBRI), Earthquake Engineering Department (EED), Ministry of Home Affairs (MHA), and Ministry of Food and Agriculture (MFA), GOI-UNDP, Geo Hazard International (GHI), SEEDS etc. The preliminary effort towards vulnerability assessment of buildings under seismic intensities has been made by the Dept. of Earthquake Engineering, Indian Institute of Technology (DEQ-IIT) and the Structural Engineering Research Centre, Chennai respectively. The damage risk assessment has not been taken up systematically except that some building damage scenario for earthquake in two or three Indian states have been made (Jain, 2000).

In this research project emphasis is given to seismic risk assessment methods. The HAZUS multi hazard loss estimation methodology is considered for evaluating earthquake loss for building structures in study area. The Dehradun is the case study city in this research for assessing buildings risks.

1.2. Relevance of study

With its vast territory, large population and unique geo climatic conditions, the Indian sub continent is exposed to natural hazardous events (BMTPC, 1999). Even today natural hazards like floods, cyclones, droughts and earthquakes are not rare in the country. While the vulnerability varies from region to region, a large part of the country is exposed to such natural hazards, which often turn into disasters causing significant injury, deaths and destruction of property.

Indian subcontinent is among the world's most earthquake prone areas. Geology predisposes sixty percent of the country's area vulnerable to earthquake disaster. Twelve percent of its land is liable to severe earthquakes of intensity IX or more on the MMI scale (NIDM, 2004). The highest seismic risk is concentrated in the north, near the border with Pakistan, Bangladesh, Bhutan, China and Nepal. This region of high seismic risk is home to 610 million people, 60% of the nation's population, containing cities with populations over 14 million inhabitants (Ministry of Home Affairs, 2001). Seven major earthquakes have struck different parts of India over a span of last 25 years. The approximate deaths, affected people and injured people in last 20 years are 32 thousand, 25 million and 200 million respectively. On 26 January 2001, a very severe earthquake struck Bhuj and shook most parts of Gujarat, causing widespread damage and devastation. Over 13,805 persons lost their lives, 167,000

persons were injured, over a million homes were damaged or destroyed and there was large-scale damage to social and physical infrastructure (GSDMA, 2002).

The India-Pakistan earthquake on October 8, 2005 is the most recent example of seismicity of Himalayan region. The IMD recorded a earthquake magnitude of 7.4 on Richter scale. The earthquake occurred in the western Himalayas in the morning at about 09.20 hrs IST (IMD, 2005). The epicentre was 125km WNW of Srinagar near Muzaffarabad, Kashmir. The earthquake was widely felt in Islamabad, Lahore, Punjub, Chandigarh, Delhi, Himachal Pradesh, Uttaranchal, Rajasthan, Haryana and adjoining areas. Nearly 20,000 people are feared dead in Pakistan and death toll in Jammu & Kashmir is reported to have crossed 600 with huge property loss. Table 1.1 provides the details of some past earthquakes in India.

Date	Event	Time	Magnitude	Max.	Deaths
				Intensity	
12 June 1897	Assam	16:25	8.7	XII	1500
8 Feb. 1900	Coimbatore	03:11	6.0	X	Nil
4 Apr. 1905	Kangra, Himachal Pradesh	06:20	8.6	X	19,000
15 Jan. 1934	Bihar-Nepal	14:13	8.4	X	11,000
31 May 1935	Quetta	03:03	7.6	X	30,000
15 Aug. 1950	Assam	19:31	8.5	X	1,530
21 Jul. 1956	Anjar	21:02	7.0	IX	115
10 Dec. 1967	Koyna	04:30	6.5	VIII	200
23 Mar. 1970	Bharuch	20:56	5.4	VII	30
21 Aug. 1988	Bihar-Nepal	04:39	6.6	IX	1,004
20 Oct. 1991	Uttarkashi, Uttranchal	02:53	6.6	IX	768
30 Sep. 1993	Killari (Latur)	03:53	6.4	IX	7,928
22 May 1997	Jabalpur, Madhya Pradesh	04:22	6.0	VIII	38
29 Mar. 1999	Chamoli, Uttranchal	12:35	6.8	VIII	63
26 Jan. 2001	Bhuj, Gujarat	08:46	7.7	X	13,805
08 Oct 2005	India-Pakistan	09.20	7.4	X	20,600

Table 1:1 List of earthquakes in India in last 110 years.

Source: (NICEE, 2005)

Buildings in urban areas are highly vulnerable structures in seismic events especially in developing countries. There is a direct relationship between the damage of civil structures to the number of casualties. Most causalities, damage and economic losses caused by earthquake result from ground motion acting upon buildings incapable of withstanding such motion (Montoya, 2002a). Damage to buildings also causes a variety of secondary effects that can be greatly destructive. Lack of capacity buildings leads to increase in risk of property loss in developing countries. Damage to essential buildings substantially increases the rate of casualties.

In the absence of risk analysis tools and databases required for earthquake risk assessment, it will be very difficult to assess the loss in post earthquake event. The risk assessment process helps in the preparing of a proper disaster management plan and plays a major role in the process of preparedness, mitigation, response and recovery. The proper implementation of building permits and controls,

building codes, and awareness-raising can effectively reduces the earthquake vulnerability to large extent.

1.3. Problem Definition

Dehradun city located in the Doon Valley in the Himalayas, has recently become the capital city of the newly formed Uttaranchal State. After becoming the capital, the city it found itself in a very critical condition. The population and infrastructure growth of Dehradun is increasing at an alarming rate. The city has been expanding in a very improper manner having huge encroachment, lack of proper infrastructure facilities, unplanned urban development etc. Moreover, the earthquake risk in the area makes the problem much more acute for the urban governing body. Therefore, a planned seismic vulnerability assessment of building structures is required to get an overview of the situation. Therefore, it is needed to assess the possible impact of upcoming seismic events. It will be more justified to evaluate earthquake risk scenarios for possible damage and systematic inventory of the elements at risk and their relative value and vulnerability.

Although no precise risk evaluation model of earthquake risk and damage assessment can be developed till date in India. The devastating effect of an earthquake can be minimized to a great extent by adopting risk models developed in other countries. HAZUS is one of those tools developed in the United States, which assesses the earthquake loss for the built environment and population in urban areas. There is a need to analyze this model for its applicability in the Indian situation. By doing analysis of this model it will be easy to identify the shortcomings in the HAZUS approach for using it in India. The possible evaluation of parameters is needed to fill the gaps identified and to find the strength of using this model in India.

The HAZUS model uses the various classifications of civil structures as well as infrastructure for assessing earthquake losses. The up to date building inventory is always necessary to assess the loss for pre and post earthquake events. The method of making building inventories is well described in this model. There is a need to study the criteria of building classification and building inventory used in this model for assessing risk for buildings under Indian conditions. The database alone cannot solve the problem of making a good inventory of buildings and infrastructure needed for loss estimation. There is need to classify this database according to the different classes and parameters that are typical for the Indian conditions. The classification is necessary to reduce the calculation for estimating losses. There are a numbers of organisations in India, which have their own classification of buildings based on various parameters. There is a need to find the sources of information required for generating this classification for typical Indian urban areas. The various organisations use different techniques for generating classes of buildings and infrastructure. This research will also focus on the criteria of classification of buildings and transport systems for the assessment of earthquake losses in urban areas. These techniques will help us in conceptualising these classifications, based on HAZUS earthquake loss estimation methodology. The study will focus on the method of collecting this database and sources of information needed to generate this dataset for rapid earthquake loss estimation.

1.4. Hypothesis

It is possible to develop and implement the methodology based on HAZUS methodology for vulnerability assessment for building structures in Dehradun city for earthquakes.

1.4.1. Main objective of the Research

The main objective of the research is to analyze the applicability of HAZUS model for the assessment of earthquake risk on building structures in Dehradun city.

1.4.2. Research objectives

- 1) To give an overview of the various earthquake risk assessment (ERA) methodologies used in India and in other countries.
- 2) To identify the parameters (for ground motion, seismic data, building inventory classification and damage curves) required in the HAZUS model for ERA for building structures in Dehradun
- 3) To evaluate the HAZUS building inventory classification in Dehradun city that can practically be used for HAZUS based ERA in Dehradun.
- 4) To map building structures in a sample area of Dehradun city and evaluate the risk using modified building classifications based on identified parameters and analyse the applicability of HAZUS model in Dehradun city.

1.4.3. Research Questions

- 1. Questions pertaining to first objective:
 - a. What are the differences in techniques and methods used in India and other countries for ERA?
 - b. What is the status of development of earthquake risk modelling in India?
- 2. Questions pertaining to second objective:
 - a. What parameters are available and what can be generated to run HAZUS model in Dehradun city for ERA for building structures?
 - b. What are the limitations of using the HAZUS model as an earthquake risk assessment tool for assessing risk for building structures in Dehradun city?
- 3. Questions pertaining to third objective:
 - a. What information is needed for the building inventory classification for earthquake risk assessment in Dehradun city?
 - b. How best can the US-based building classification be adopted for ERA for building structures in Dehradun?

- 4. Questions pertaining to fourth objective:
 - a. What modifications are needed in terms of parameters to adopt HAZUS model for ERA for buildings in Dehradun city?

1.5. Expected output

The research will give an overview of current development of methods for ERA in India and other countries. It will also discuss the advantages and limitations of Indian method of ERA. The comparison between HAZUS method and Indian methods will be explained in detail. The availability of ground motion data, seismic data, and building data required for ERA using HAZUS method will be discussed. The various sources of generating the missing data required for HAZUS based ERA in Dehradun will be explained in this research. The method of generating the building database and building inventory will be a part of this research. The research will also focus on the analysis of risk assessment in sample area of Dehradun city using HAZUS methodology. An evaluation of use of HAZUS methodology for ERA of building structures in Dehradun city.

1.6. Study Area

The city of Dehradun is the interim capital of Uttaranchal in North India and the largest city in the Uttaranchal state. Uttaranchal is situated in the foothills of the Himalayas, which is highly susceptible to earthquakes. The Main Boundary Thrust (MBT) and the Main Frontal Thrust (MFT) are the main active features in Uttaranchal, thus have the greatest potential for a future great earthquake (M >7.5) at any time (Sharma, 2003a). Garhwal Himalayas has experienced quite strong earthquakes like Uttarkashi earthquake (M 6.6) in 1991 and Chamoli earthquake (M 6.8) in 1999 (EERI, 1999). Dehradun city lies in the seismic zone IV and has a population of about 0.5 million (BMTPC, 1999). The Kangra earthquake (M 8.6) of 1905 had a rupture zone which extended up to Dehradun city and there are records of damage at several parts of Dehradun city (Middlemiss, 1910).

1.7. Research Methodology

The research methodology has been shown in schematic flow chart in the figure 1.1. The whole research work has been divided into four major parts. The first part of the methodology deals with the literature review of general terms related to ERA and review of various ERA methods available in India and in other countries. The second part deals with the identification and generation of data required for ERA in Dehradun using the HAZUS. The third part deals with the evaluation of HAZUS building inventory classification and possible modification to use it for ERA in Dehradun city. The fourth part of the methodology deals with the data preparation and risk assessment of building structure in a sample area of Dehradun city. It also includes the analysis of applicability of the HAZUS model in a sample area of Dehradun.

Research Methodlogy

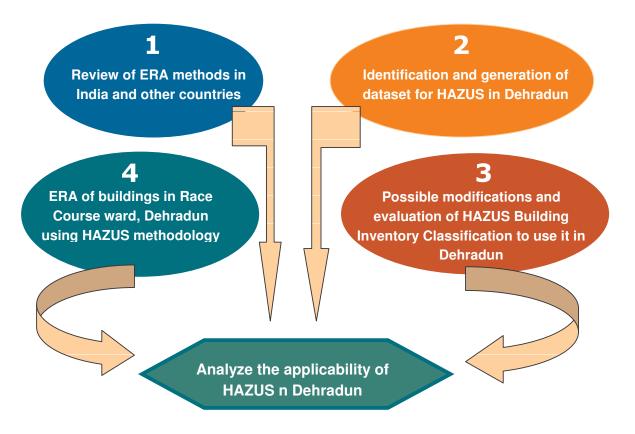


Figure 1-1: Schematic diagram of research methodology

1.8. Structure of Report

This report has been divided into seven chapters mentioned below.

Chapter 1: Introduction

This chapter provides the relevance of this research, problem statement, research objectives and research methodology. A small introduction of the study area is also included in this chapter. The overview of the research methodology is also given in this chapter.

Chapter 2: Literature Review

The chapter discusses the general terms used in ERA and effect of earthquake on building structures. It also gives the general idea about the risk assessment process.

Chapter 3: Review of earthquake risk assessment methods

The chapter includes the detailed discussion on the various ERA methods used in India and in other countries. The comparison of Indian method with non-Indian method is also included in this chapter.

Chapter 4: Study Area

This chapter gives an overview of the study area – Dehradun city. It also gives a general idea about its geographical location, area and its susceptibility for seismic events in the future

Chapter 5: Data Preparation

This chapter deals in the data collection and data preparation. It explains the method of collecting data from academic, government and semi government institutes and organizations. It also describes the various datasets used for data processing and database generation for the study area

Chapter 6: Result and Discussions

This chapter presents the results of risk assessment of building structures of study ward in Dehradun city using the HAZUS methodology.

Chapter 7: Conclusions and recommendations

This chapter states the conclusions and recommendations of the present study.

2. Literature Review

This chapter reviews literature on earthquake terminology and general terms used in the earthquake risk assessment for building structures. It also covers study of vulnerable elements of building and factors affecting building vulnerability. The chapter also covers affect of earthquake on various building structures types exist in India. It also focuses on the general methods of earthquake risk assessment. The usefulness of remote sensing and GIS is also reviewed in this chapter.

2.1. Hazard

Hazard is the probability of occurrences of a potentially damaging phenomenon within a specified period of time and with in a given area (Smith, 2001). Most of the studies classify hazards into two according to their nature; namely natural hazard and human induced hazards. The natural hazard again can be subdivided into geological hazard, hydro meteorological hazard and biological hazard (UNDP, 2004).

2.1.1. Earthquake hazard

An earthquake is a sudden and violent shaking of the earth when large elastic strain energy released spreads out through seismic waves that travel through the body and along the surface of the earth (Murty, 2005). For example, the energy released during the 2001 Bhuj (India) earthquake is about 400 times that released by the 1945 Atom Bomb dropped on Hiroshima.

The earth crust consists of portions called plates. When these plates contact each other, stresses arise in the crust. The areas of stresses on the plate boundaries that release accumulated energy by slipping and rupturing are known as faults. A rupture occurs along a fault when accumulated stresses overpass the supporting capacity of the rock mass and the rock rebounds under its own elastic stress until the stress is relieved. The point of rupture is called the focus or hypocenter and may be located near the surface or deep below it. The point on the surface vertically above the focus is termed as epicentre of the earthquake. The fault rupture generates vibrations called seismic waves that radiates from the focus in all directions.

2.1.2. Types of earthquakes

The earthquakes are divided into two categories based on their plate movement (Murty, 2005). These are inter-plate earthquakes and intra-plate earthquakes. The inter-plate earthquakes occur along the boundaries of the tectonic plates (e.g., 1897 Assam, India earthquake, M8.7). The intra-plate earthquakes occur within the plate itself away from plate boundaries (e.g., 1993 Latur earthquake, M6.2). In both types of earthquakes, the slip generated at the fault during earthquakes is along both vertical and horizontal directions (called Dip Slip) and lateral directions (called Strike Slip). Figure 2.1 shows the types of slip generated at the faults.

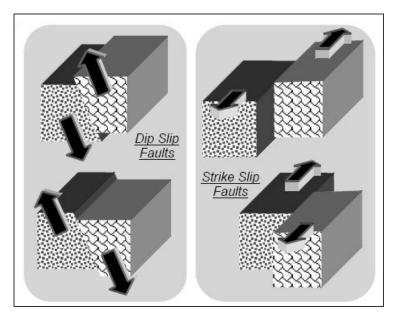


Figure 2-1: Types of slips generated at the faults

Source: (Murty, 2005)

2.1.3. Measurement of Earthquakes

2.1.3.1. Earthquake Magnitude

The magnitude of an earthquake is a quantitative measure of the amount of energy released at the source, the focal area. It is estimated from instrumental observations. The oldest and most popular measurement of an earthquake is the Richter scale, defined in 1936. Since this scale is logarithmic, an increase in one magnitude signifies a 10-fold increase in ground motion or roughly an increase of 30 times the energy release. Thus, an earthquake with a magnitude of 7.5 releases 30 times more energy than one with a 6.5 magnitude.

2.1.3.2. Earthquake Intensity

The intensity is a qualitative measure of the actual ground shaking at a location during an earthquake, and is assigned as Roman Capital Numerals. Two commonly used intensity scales are the Modified Mercalli Intensity (MMI) scale that was first developed by Mercalli in 1902 and Medvedev-Sponheuer-Karnik (MSK) scale (1964). Both scales are quite similar range from I (least perceptive) to XII (most severe). Both expresses the intensity of earthquake effects on people, structures and earth's surface in steps from I to XII. The MMI scale is the most widely used intensity scale in most of the countries. It is important to note that many authors, amongst them Sauter (1989), consider that intensities between I and IV are irrelevant for seismic risk analysis as 90% of damage occurs from scale VIII upwards (Montoya, 2002b). Table 2.1 gives the approximate relationship between earthquake intensity and magnitude.

Earthquake Magnitude	Maximum expected	Radius of area where felt	Size of area where felt
	Intensity	(Km)	(Km Sq)
4.0-4.9	IV-V	50	7,700
5.0-5.9	VI-VII	110	38,000
6.0-6.9	VII-VIII	200	125,000
7.0-7.9	IX-X	400	500,000
8.0-8.7	XI-XII	800	2,000,000

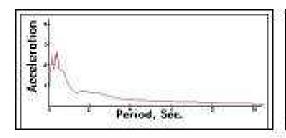
Table 2:1: Relationship between earthquake magnitude and intensity.

Source: (Shukla, 2004)

2.2. Terminology

Resonant Frequencies: When the frequency contents of the ground motion are centred around the building's natural frequency, the building and the ground motion are in resonance with one another (MCEER, 2005). Resonance tends to increase or amplify the building's response. Because of this, buildings suffer the greatest damage from ground motion at a frequency close or equal to their own natural frequency.

Response Spectra: A representation of response of building's range to ground motion at different frequency content is known as response spectrum. A response spectrum is a kind of graph, which plots the maximum response values of acceleration, velocity and displacement against period and frequency. Figure 2.2 shows the typical shape of response spectra.



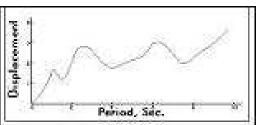


Figure 2-2: Typical shape of response spectra

Source: (MCEER, 2005)

Natural Frequency: The building's vibrations tend to center around one particular frequency, which is known as its natural or fundamental frequency (MCEER, 2005). Whereas the frequency is the number of times per second that the building will vibrate back and forth. The natural frequency of an element is given by formula (DST, 2004)

$$f_n = \frac{1}{2\pi} \sqrt{\frac{k}{m}}$$

where

f = fundamental natural frequency in Hz

k = stiffness of the building

m = mass of the building in Kg

The building's natural period is simply the inverse of the frequency: The time taken for each complete cycle of oscillation is called Fundamental Natural Period T of the building and T is given by:

T = 1/f

This means that a short building with a high natural frequency also has a short natural period. Conversely, a very tall building with a low frequency has a long period. The value of T depends on the building flexibility and mass. Fundamental natural period T is an inherent property of a building. Any alterations made to the building will change its T. Table 2.2 shows the approximate frequencies of different stories building.

Type of object or structure	Natural frequency (Hz)
1 storey buildings	10
2 storey buildings	5
3-4 storey buildings	2
tall buildings	0.5-1.0
high rise building	0.17

Table 2:2: Example of typical natural frequencies depending on building type

Source: Kramer, 1995

Damping: The building motion during an earthquake has a complex vibratory nature. The building moves back and forth in many different horizontal directions. In a building undergoing an earthquake, damping is the decay of the amplitude of a building's vibrations due to internal friction and the absorption of energy by the building's structural and non-structural elements. All buildings possess some intrinsic damping. The more damping a building possesses, the sooner it will stop vibrating. It is expressed as a percentage of critical damping.

Critical Damping: In a building undergoing an earthquake, when internal and or external friction fully dissipates the energy of the structural system during its motion from a displaced position to its initial position of rest, the structure is considered to be critically damped. Thus the damping beyond which the motion of the structure will not be oscillatory is described as critical damping.

Spectral Acceleration: The spectral acceleration (S _A) is approximately what is experienced by a building, as modeled by a particle on a massless vertical rod having the same natural period of vibration as the building. The unit of spectral acceleration is g (gravity).

Spectral Displacement: The spectral displacement (S _D) is illustrated as displacement of a modeled particle on a certain damping mass-less rod, which is driven on its base by the seismic record.

2.3. Effect of earthquakes on buildings

The primary effect of an earthquake is shaking of a building or infrastructure. During an earthquake, a building is shaken in all possible directions. The shaking loosens the joints of different components of building that leads to subsequent damage or collapse. Figure 2.3 shows the effect of earthquake on masonry buildings.

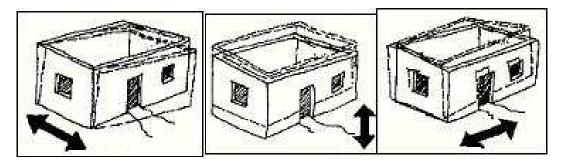


Figure 2-3: Effect of earthquake on masonry buildings

Source: (IAEE, 1986)

2.3.1. Failure mechanism of buildings

Buildings as a whole and all their components are badly shaken during severe earthquakes. Since earthquakes are earth movements (which, in effect cause the ground to move under a building), the forces that occur in a building come from the inertia of its own mass (IAEE, 1986). Therefore the force is proportional to the mass. Hence, the heavier the building, the more will be the inertia force i.e. the earthquake load on the building. Inertia force caused on any mass (m) can be described by the formula. Figure 2.4 shows failure the mechanism of building.

F = m.a, where 'a' is the acceleration in m/s on the mass 'm' in Kg

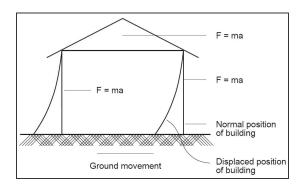


Figure 2-4: shows the failure mechanism of building

Source: (IAEE, 1986)

As the base of the building moves in an extremely complicated manner, inertia forces are created throughout the mass of the building and its contents. It is these reversible forces that cause the building to move and sustain damage or collapse. Additional vertical load effect is caused on beams and

columns due to vertical vibrations. Being reversible, at certain instants of time the effective load is increased, at others it is decreased.

2.3.2. Failure mechanism of RC framed buildings

The two primary building materials used in reinforced concrete (RC) framed buildings are cement concrete and reinforcing steel bars. A typical concrete building is made of horizontal components (beams and slabs) and vertical components (columns and walls), and supported by foundations that rest on ground. The building system comprising of RC columns and connecting beams is called a RC Frame. The RC frame participates in resisting the earthquake forces. Earthquake shaking generates inertia forces in the building, which are proportional to the building mass (Murty, 2005). In RC buildings the vertical spaces between columns and floors are usually filled-in with masonry walls to demarcate a floor area into functional spaces (rooms). So, due to their heavy weight and thickness, these walls attract rather large horizontal forces. As masonry is a brittle material, these walls develop cracks once their ability to carry horizontal load is exceeded, but they help to share the load of the beams and columns until cracking.

RC framed buildings fail during large earthquakes mainly due to the following reasons: -

- Columns are overstressed and burst if there is not enough strength
- Failure of RC elements (beam, slab, column) at the place of poor ductile detailing
- Collapse of cladding, partition walls and infill walls

2.3.3. Failure mechanism of masonry buildings

Masonry buildings are brittle structures and one of the most vulnerable parts of the entire building stock under strong earthquake shaking. The seismic behavior of a masonry building during an earthquake-generated vibration strongly depends upon how the walls are interconnected and anchored at the floor and roof level (Murty, 2005).

The ground shakes simultaneously in the vertical and two horizontal directions during earthquakes. These forces travel through the roof and walls to the foundation. The main emphasis is on ensuring that these forces reach the ground without causing major damage or collapse. Of the three components of a masonry building (roof, wall and foundation) the walls are most vulnerable to damage caused by horizontal forces due to earthquake (Murty, 2005). Horizontal inertia force developed at the roof transfers to the walls acting either in the weak or in the strong direction. If all the walls are not tied together like a box, the walls loaded in their weak direction tend to topple.

2.4. Seismic Risk Assessment

The Seismic risk assessment process can be divided into four main groups namely:

a) Hazard assessment b) elements at risk mapping c) vulnerability assessment and d) risk assessment

2.4.1. Hazard assessment

Hazard assessment quantifies the physical character of a hazard, including probability of occurrence, magnitude, intensity, location and influence of geological factors. There are two main methods of

hazard assessment namely seismic macrozonation, which is done at regional scale in order to evaluate the maximum acceleration for different return periods, and the seismic microzonation, which determines the influence of site effects on the amplification of seismic acceleration, due to soil characteristics, topographic variations and the effect of buildings. Seismic microzonation can be subdivided into the probabilistic method and the deterministic method.

Deterministic Seismic Hazard Analysis (DSHA) is based on the calculation of the acceleration related to a particular earthquake scenario, which occurs at the closest possible distance from the site of interest, without considering the likelihood of its occurrence during a specified exposure period. This approach analyses the historical records of seismic events. The probabilistic method evaluates the possibility of exceeding a particular level of ground motion at a site during a specific time interval. This approach for seismic hazard analysis was developed by Cornell (1968). Probabilistic Seismic Hazard Analysis (PSHA) can easily incorporate model and parameter uncertainties (Panel on Seismic Hazard Evaluation, 1997).

2.4.2. Elements a risk mapping

Elements at risk refer to the population, buildings, civil engineering woks, economic activities, public services, utilities, and infrastructure etc, that are at risk in a given area (VanWesten, 2001).

Each of these elements at risk has its own characteristics, which can be spatial (related to the location in elation to the hazard), temporal (such as the population, which will differ in time at a certain location) and thematic characteristic (such as the material type of buildings. The mapping of elements at risk such as buildings is one of the prerequisites for assessing building loss. Building stock is generally subdivided into three main groups; namely general building stock, essential facilities and high potential loss facilities (NIBS, 2002). The general building stock includes residential, amusement, recreational, office, and commercial buildings. Where-as essential facilities defined as buildings, which are vital for the operation during and after catastrophic events in order to provide rescue and for maintaining safety. There are some more building types, which come under the high potential loss facilities; namely nuclear power plants, chemical plants and dams.

2.4.3. Vulnerability assessment for buildings

Physical vulnerability is defined as the degree of loss to a given element or set of elements at risk resulting from the occurrence of natural phenomenon of a given magnitude. It is expressed on a scale from 0 to 1 (UNDP, 2004). Earthquake vulnerability of a building is defined as the amount of expected damage induced to it by a particular level of earthquake intensity (UNDP, 2004). Vulnerability is a function of magnitude of an event and the type of elements at risk. There are different types of vulnerability; physical, social and economic. Especially the social vulnerability like population changes constant through time. It can be in the form of urban expansion or change in population (VanWesten, 2001). For example in a seismic event the vulnerability derived from the magnitude of earthquake and the elements, which are at risk. These elements define weight of vulnerability. The more elements at risk higher will be the vulnerability.

The vulnerability assessment is to identify the vulnerable conditions of buildings that are exposed to natural hazards. It describes as the probability of failure of a structure under different levels of ground shaking. There are two methods for the analysis of building vulnerability; namely qualitative and

quantitative methods (Singh, 2005a). The qualitative method is based upon the statistical evaluation of past earthquake damage. This method is suitable for non-engineering buildings that have the same type of building character. The quantitative method is based upon the numerical analysis of the structure. The buildings with the same material and construction type are grouped into one class. The performance of the buildings is predicted based upon design specifications and construction details.

The vulnerability of buildings is normally represented by vulnerability functions. The function relates the mean damage potential of a particular class of building to the hazard intensity. There are a number of principal prerequisites for developing vulnerability curves (Krovvidi, 2001). These are economic loss data, the hazard for which the environment was subjected to and building inventory based on building characteristics. The other factors, which contribute to the development of a sound vulnerability function, are hazard-structure interaction, building damage statistics and knowledge of socio economic conditions of the region.

2.4.4. Risk Assessment for buildings

Risk is the actual exposure of something of human value to a hazard and it is often regarded as the product of probability and loss (Smith, 2001). It may be expressed mathematically as a function of hazard, vulnerability and amount. The amount refers the quantification of the elements at risk. For example rebuilt or replacement costs of buildings, loss of economic activities and number of people (VanWesten, 2001). These definitions are illustrated by an example. Suppose two people are living at a same region in two different houses. One is living in an engineering building and the other is living in a non-engineering building. In a case of a seismic event the risk in terms of hazard and amount (persons) is same for both but the risk in terms of vulnerability is higher for a person who is living in a non-engineering building. Thus an earthquake hazard can exist in an uninhabited region but an earthquake risk can occur only in an area where people and their possessions exist. The risk is further indirectly proportional to the capacity (VanWesten, 2001). Capacity is qualitatively expressed in terms of positive managerial, operational resources and procedures for reducing risk forces. The mitigation and preparedness efforts can be considered to increase the capacity. Mitigation activities involve assessing the risk and reducing the potential effect of disasters. A preparedness activity consists of planning how to respond in case of emergency or disaster occurs. Therefore the risk function can be represented as:

Risk = f(H, V, A, C)

Where

H=Hazard expressed as probability of occurrence within a reference period (e.g. year),

V= Physical vulnerability of a particular type of element at risk (from 0 to 1),

A= Amount or cost of a particular element at risk (e.g., number of buildings, number of people, etc,)

C= Capacity expressed in terms of positive managerial, operational resources and procedures for reducing risk forces

The risk can be classified into two main categories; namely involuntary risk and voluntary risk (Smith, 2001). Involuntary risks are those risks, which are not knowingly undertaken. They often relate to rare events with a catastrophic potential impact. All natural hazards fall into this category. Voluntary risks are those risks, which are more willingly accepted by people through their own actions. Man made hazards including technological hazard are placed in this group.

Risk assessment includes detailed quantitative and qualitative understanding of risk, its physical, social, economic and environmental factors and consequences (UNDP, 2004). According to Kates and Kaspierson (1983) risk assessment is comprised of three distinct steps; namely risk identification, risk estimation and risk evaluation. Risk identification includes the collection of information about the hazardous event, its occurrence and nature. Risk estimation includes the estimation of the probability and impacts of such an event and risk evaluation includes the evaluation of the consequences of the derived risk. Building vulnerability assessment done by field expert gives always better result as compare to others. For example – The construction engineer can judge better the vulnerability of the building structure than others. Also vulnerability/capacity assessments make use of methods such as community based mapping techniques, in which the community at risk plays an active role. Therefore field data collection can be considered as an essential component in risk assessment.

2.5. Factors affecting buildings vulnerability

The earthquake engineering community believes that there are four virtues on which the vulnerability of building depends (IAEE, 1986).

- 1. Good Structural Configuration
- 2. Lateral Strength
- 3. Adequate Stiffness
- 4. Good Ductility

2.5.1. Structural Configuration

2.5.1.1. Structural Design

A building is a typical composition of structural and non-structural elements. The structural elements include vertical components (such as columns and walls) and horizontal components (such as floors, roofs, beams and girders). The performance of any building in an earthquake mainly depends upon these structural elements.

Structural elements are those elements of the building that help to support the horizontal and vertical forces acting on it. There are basically two types structural framing possible to withstand gravity and seismic load, viz. load bearing wall construction and framed construction. The framed constructions can be used for a greater number of storeys compared to a bearing wall construction. The strength and ductility can be better controlled in framed constructions through design. The strength of the framed construction is not affected by the size and number of openings. Non-structural elements are those elements of buildings that are connected to a structural system but without a load carrying system. The non-structural elements include varieties of different architectural, mechanical, electrical components and other house contents. According to the response to the earthquake motion and in order to assess their damage, these elements are classified into two classes; acceleration sensitive nonstructural elements and drift sensitive non-structural elements. The components comes under acceleration sensitive are cantilever, parapets, racks, cabinets, piping system, HVAC system, lighting fixtures etc. They are called acceleration sensitive because their cause of damage floor acceleration. The components comes under drift sensitive are nonbearing walls, partitions, exterior wall panels, veneer, finishes and penthouses. They are called drift sensitive because their cause of damage is an interstory drift.

2.5.1.2. Shape of the Building

An important feature is the general planning and design consideration of proposed buildings. The general planning includes symmetry and regularity in the overall shape of a building. The building should be kept symmetrically about both the axes. Asymmetry leads to torsion during earthquakes and is not very stable. Simple rectangular shapes behave better in an earthquake than shapes with many projections. Torsion effects of ground motion are pronounced in long narrow rectangular blocks. Figure 2.5 shows the typical shapes of building.

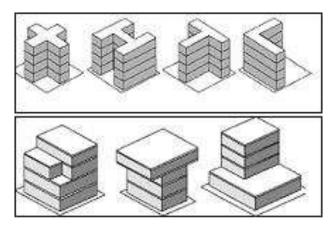


Figure 2-5: Example of typical shapes of building

2.5.1.3. Height and Number of storeys

Height is perhaps one of the most important elements in a building's configuration. When the height of the building is bigger, then the displacement of the buildings is greater. In tall buildings with large height-to-base size ratios, the horizontal movement of the floors in an earthquake during ground shaking is large. In short but very long buildings, the damaging effects during shaking are many. And, in buildings with large plans area like warehouses, the horizontal seismic forces can be excessive to be carried by columns and walls. Buildings that have fewer columns or walls in a particular storey or with unusually tall storeys tend to damage or collapse, which is initiated in that storey. Many buildings with an open ground storey intended for parking are more prone to collapse or were severely damaged. Among those multi-storey buildings that collapsed in Gujarat during the 2001 Bhuj earthquake, a majority of them had the ground storey left open for parking convenience without any walls built between the columns (NDMD, 2004).

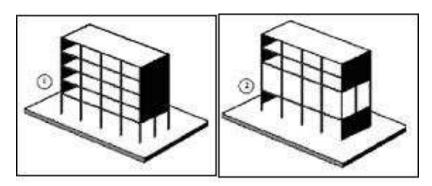


Figure 2-6 : Example of soft story in building Source: (Murty, 2005)

2.5.1.4. Building Proximity

The separation distance between buildings is an important factor for preventing it from hammering or pounding damage in case of a seismic event. A physical separation of 3 to 4 cm between two blocks throughout the height above the plinth level will be adequate for up to 3 storyed buildings (IAEE, 1986). The separation section can be treated just like expansion joints or it may be filled or covered with a weak material, which would easily crush and crumble during earthquake shaking. Such separation may be considered in larger buildings since it may not be convenient in small buildings. Every multistoried building can swing according to its own natural frequency during an earthquake. The probable displacement of a building can be found out from a structural analysis. The minimum separation distance between two buildings must be 4 % of the height of the buildings - this is basically with the assumption that most structures will not drift more than 2 % during the occurrence of an earthquake (FEMA, 1998).

2.5.2. Lateral Strength

The lateral strength of any building is the maximum lateral force that it can resist, such that the damage induced in it does not result in collapse. The lateral force largely depends upon the total weight of the superstructure and stiffness of the building (IAEE, 1986). Larger the stiffness for given mass, shorter the fundamental period of vibration of the structure. The inertia forces are proportional to the mass of the building and only that part of the loading action that possesses mass will give rise to seismic force on the building. The lighter the material, the smaller will be the seismic force.

2.5.3. Building Stiffness

The height of a building is related to another important structural characteristic: the building flexibility. Taller buildings tend to be more flexible than short buildings. Consider a thin metal rod. It is very difficult to bend a short metal rod by hand of same diameter than a rod of somewhat longer in length. A building behaves similarly. We say that a short building is stiff, while a taller building is flexible. Obviously, flexibility and stiffness are really just the two sides of the same coin. If something is stiff, it isn't flexible and vice-versa.

2.5.4. Ductility

Ductility is the ability to undergo distortion or deformation—bending under severe earthquake shaking even after yielding. Different individual buildings shaken by the same earthquake respond differently. It is far more desirable for a building to sustain a limited amount of deformation than for it to suffer a complete breakage failure. The ductility of a structure is in fact one of the most important factors affecting its earthquake performance. The building should possess enough ductility to withstand the size and types of earthquakes it is likely to experience during its lifetime.

2.6. Foundation

Buildings, which are structurally strong to withstand earthquakes sometimes, fail due to an inadequate foundation design. Tilting, cracking and failure of superstructures may result from soil liquefaction and differential settlement of footing. Certain types of foundations are more susceptible to damage than others. For example, isolated footings of columns are likely to be subjected to differential

settlement particularly where the supporting ground consists of different or soft types of soil. Mixed types of foundations within the same building may also lead to damage due to differential settlement. Very shallow foundations deteriorate because of weathering, particularly when exposed to freezing and thawing in the regions of cold climate. Buildings can be constructed on firm and soft soils but it will be dangerous to build them on weak soils. Hence appropriate soil investigations should be carried out to establish the allowable bearing capacity and nature of soil. Weak soils must be avoided or compacted to improve them so as to qualify as firm or soft.

2.7. Building Material and Construction Technique

Construction material and technique affect the seismic performance of a building. The construction technique is largely depending upon the building material used for building construction. Two types of construction techniques generally used in Indian context. These are load-bearing construction and RC framed construction (Sur, 2005). The building materials used in construction of load bearing structure and RC framed structures are given in the table below. A building constructed of bricks in cement mortar will behave much better than constructed of bricks in mud mortar, provided all other parameters remain the same. To resists the internal forces caused by earthquakes it is helpful if the materials perform well both in compression and in tension. Materials, which perform well only in compression, are often reinforced by other materials with good tensile strength qualities. Table 2.3 shows the commonly used building construction techniques and building materials in Dehradun.

Construction	Structural	Wall	Type of	Roof	Floor
Technique	Elements	Material	Mortar	Material	Material
Load	Brick column	D -: -1-	M1	RBC, GI,	DDC DCC
bearing		Brick	Mud, cement	RCC	RBC, RCC
RC framed	RCC column, beam	Brick, RCC	Cement	RCC	RCC

Table 2:3: Building construction techniques and building materials in India

2.8. Usefulness of remote sensing and GIS in ERA

Remote sensing data by virtue of its repetitive characteristics provides timely and reliable information on human resources and their surrounding. This information is an important input for sustainable urban management process and emergency response plan to a hazard at micro level. In case of fast growing towns and cities, the need to update this information has much more significance. Remote sensing data can be effectively used to update the information as well as mapping and analysis. The high-resolution satellite imagery helps to prepare up to date base maps of a city over which various GIS analyses can be done.

A Geographical Information System (GIS) is a computer-based system designed to store, analyze and display geographic information. A database generated in GIS environment provides a powerful tool for analysis and integration of seismic zonation study. GIS technology allows user to display the impacts of the geographical distribution from different earthquake scenarios and assumptions. The overlay of input data and output data on thematically shaded maps of the region allows the users to extract necessary information within a GIS platform. On the basis of input data, GIS can evaluate and identify the buildings under vulnerable condition, the structures that resist earthquake damage, the

various elements under risk as well as can help in developing emergency response plan within a particular region. An advantage of GIS technology is that once the inventory database is built, it can be used for other purposes such as city planning, public works or emergency preparedness for other types of natural disasters.

2.9. Summary

This chapter gives an overview of the nature of earthquake hazard, its occurrences and effect on building structures. It reviews the general terms used in earthquake risk assessment. It also reviews the characteristics of structural and non-structural parts in the building system and their vulnerability in the earthquake. It explains the mechanism of failure of various components in building system in earthquake. Among all the factors discussed above, the structural configuration plays the most important role in assessing the vulnerability of the any building. The structural configuration of masonry buildings includes aspect like a) overall shape and size of the building and b) distribution of mass and lateral load resisting elements across the building. The structural configuration of RC framed buildings includes the shape of structure and strength of its structural elements. The RC framed building should carry two types of loading namely gravity loading (due to self weight and contents) and earthquake loading to remain safe in earthquake shaking. There should be a strength hierarchy in RC framed buildings. The columns should be stronger than beams; foundation should be stronger than columns. The connection between beams-columns and columns-foundations should not fail so that beams can safely transfer forces to columns and columns to foundation. The detailed study of technical aspect of building vulnerability gives us the in deep understanding of assessment of the building vulnerability in a seismic event. The use of remote sensing and GIS plays important role in ERA of buildings. The advance technology can effectively reduce the impact of earthquake in urban areas and help in developing emergency response plan.

3. Review of risk assessment methods

This chapter reviews literature on methods and approaches of earthquake risk assessment in India and other countries. It also reviews the history of earthquake risk modelling and development of risk evaluation in the world. The damage algorithm of probability calculation by HAZUS methodology is explained in detail. The study will be useful to understand the various aspects of using risk assessment methods and their applicability in risk assessment processes.

3.1. Risk Modelling

3.1.1. Historical Background

The process of risk estimation began in the late 19th century, with the systematic recording of weather, stream heights and then earthquakes (Charles, 2005). The first to address the benefits of mitigation was John R. Freeman, whose classic work *Earthquake Damage and Earthquake Insurance*, written in 1932, reviewed the known history of damaging events. In the 1980s the modelling firms (AIR, EQECAT, RMS) emerged, but had very lean times until the Northridge earthquake in 1994 in Southern California and Kobe earthquakes in 1995 in Japan. The 1990s saw the rapid development of loss modelling, supported by the insurance industry, and also by the state of California. California then supported development of a user-friendly benefit-cost analysis package required by Federal Emergency Management Agency (FEMA). FEMA then developed standardized earthquake loss modelling methodology and software package HAZUS (Hazard United States) in the 1990s, and subsequently extending the concept to flood and hurricane (HAZUS-MH-MR1, released in 2005).

3.1.2. Recent Development

With regard to natural hazards, the developed countries like USA, Japan remains the centre of innovation and application for risk modelling. Most of the risk estimation methodologies have been developed in the United Sates over the last two decades. These risk assessment methods can be categorized into commercial and non-commercial ones (VanWesten, 2001). The model as well as software for using the commercial methods is not freely available. The commercial methods are developed by companies, such as MunichRe, RiskLink (RSM), EQEHAZARD (EQECAT), CATMAP (AIR), CATEX (CATEX), EPEDAT (Early Post-Earthquake Damage Assessment Tool, ImageCat), REDARS (Risk from Earthquake Damage to Roadway Systems) and Risk Management Solutions (RMS) etc.

The non-commercial methods are those for which software as well as technical support from company is freely available. The manuals for using these models can be downloaded from internet. Most of these methods are developed by National authorities such as US Army Corps of Engineers (USACE), Hydrologic Engineering Centre (HEC), Federal Emergency Management Agency (FEMA), and National Institute of Building Sciences (NIBS). In Canada, the Natural Hazards Electronic Map and Assessment Tools Information System (NHEMATIS) has been developed by Emergency Preparedness Canada. In other developments, the United Nations, International Decade for Natural Disaster Reduction (IDNDR) in 1997 funded the RADIUS (Risk Assessment Tools for Diagnosis of Urban

Areas Against Seismic Disasters) project, a spreadsheet-based earthquake loss estimation tool. The RADIUS method is developed in United States by GeoHazard International (GHI). The major development in the United States has been HAZUS – a standardized loss estimation methodology. The HAZUS software is publicly available. It has been funded by Federal Emergency Management Agency (FEMA) and developed by National Institute of Building Sciences (NIBS) in 1997. The first version of HAZUS was made only for earthquake loss estimation. The recent HAZUS MH as extended to multi hazard loss estimation and includes hazards such as earthquake, landslide, fires, debris, hurricanes and floods. Outside of the United States, some are cited EXTREMUM in Russia, Taiwan Earthquake Loss Estimation System (TELES) in Taiwan which was developed from HAZUS method. The European Union is currently funding a major project LESSLOSS to develop something like HAZUS for earthquakes risk assessment in Europe. Although most of these methods have been developed in the United States, they are applied worldwide, depending on data availability.

3.2. Current Approaches to Seismic vulnerability

Two types of models currently exist to estimate earthquake damage: empirical (based on statistical data) and analytical (based on modeling). Both approaches attempt to estimate losses for broad classes of buildings as a function of seismic shaking intensity, e.g., modified Mercalli intensity (MMI) or spectral intensity (S_{ω} , S_{ν} , etc.).

Empirical damage data is produced from past event (Montoya, 2002a). The statistical distribution of damage grades is given by damage probability matrix and fragility curves (Kiremidjian et al., 2004). A relationship may be created between damage and shaking intensity. A plot of this relationship is referred to as a vulnerability function. Analytical damage data is produced either from a computer simulation or from a small-scale model tested on a shaking table. This method is based on simplified models, which include a great deal of uncertainty. The vulnerability of a set of buildings is given by a capacity curve. This capacity curve is obtained by push over analysis on prototype buildings. The two most important examples are ATC-13 (Applied Technology Council, 1985) and HAZUS.

The commonly used risk assessment methodologies have been discussed in detail in this section. These are RADIUS method (USA), HAZUS method (USA) and TELES method (Taiwan). The emphasis will be given to the building parameters, type of building classification and damage function used in the evaluation of building risk.

3.2.1. RADIUS Methodology for building loss assessment

Radius is one of those tools, which have been extensively used for risk assessment by different groups. The initiative was taken by secretariat of IDNDR in 1996 to launch this method. The prime objective of this method was to provide the simple tool, which by assessing earthquake risk reduces the seismic risk in urban areas, particularly in developing countries. The methodology calculates risk at the ward level. Most of the existing risk management techniques and methodologies have been developed in industrialized countries and, as such, cannot be transferred directly to developing countries (Villacis, 1999). This methodology has been developed through actual projects in such cities as Quito, Ecuador, and Kathmandu, Nepal. The schematic diagram of RADIUS methodology is given in fig 3.1

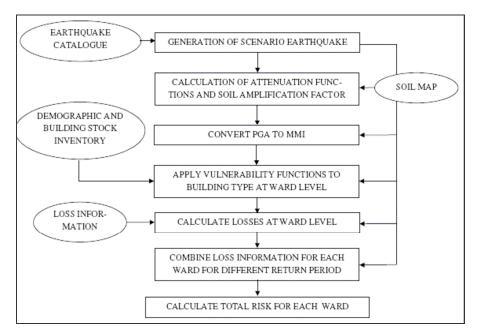


Figure 3-1: Flow chart of Radius methodology

Source: (Tung, 2004)

Figure 3.1 shows the flow chart of Radius methodology. This methodology divides the building class into 10 categories based on their material type, construction type, seismic code, occupancy type and number of stories (Villacis and Cardona, 1999) (annexure 15). This classification is based on the common building type in Latin American cities. The number of each type of building in each mesh is estimated by density of buildings with a weight called "Mesh weight".

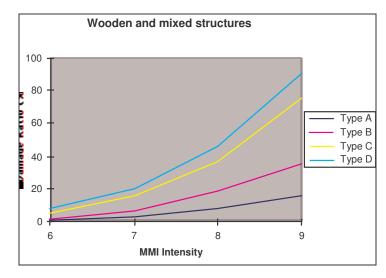


Figure 3-2: Typical vulnerability curve of Radius method

Source: (Villacis and Cardona, 1999)

Vulnerability functions are determined as a function of acceleration/ MMI based on damage observed during past sample earthquakes (Villacis, 1999). The damage levels considered in this method are collapse and heavy damage.

The vulnerability function used in this methodology generated from vulnerability assessment, including two steps (Villacis and Cardona, 1999):

- a) Identify all the existing structural and infrastructure types of the city and then select representative ones.
- b) Existing vulnerability functions for the selected types are calibrated using data of past observed damage as well as the opinions and/or studies of local experts. For important and critical facilities, individual vulnerability studies are carried out.

3.2.2. HAZUS Methodology for building loss assessment

The National Institute of Building Sciences (NIBS) developed a methodology referred to as HAZUS (Hazard US) for multi hazard risk assessment. This methodology was developed by FEMA in 1997 to assess the earthquake loss within the USA. The latest version of this methodology launched in January 2005 is called HAZUS MH MR-1, which also includes other hazards like floods and hurricanes. It uses GIS software to map and display hazard data and result of probable risk estimate for buildings and infrastructures. The model works on the classification of various components like population, building, transport system, lifeline utilities and hazardous materials based on inventory of these elements.

One of the major components of this methodology is an extensive database of hazard and element at risk required for risk assessment. In HAZUS, an inventory is made of the general building stock is calculating the total area of groups of buildings with specific characteristics based on a census tract. The methodology is therefore based on the tracts as the smallest geographical unit. Census tracts are divisions of land that are designed to contain 2500 to 8000 inhabitants. Census tract boundaries never cross country boundaries; hence they can completely and uniquely define all the area within a country.

The occupancy type inventory (annexure 4) of the general building stock in the HAZUS methodology was prepared on the basis of its general and specific building occupancy. The main aim of making a building inventory is to group buildings with similar characteristic and classify them it in a group of pre-defined building class. In this method the classifications of each component are done according to their construction type, material type, and structural type. The buildings are classified into five structural framing such as wood framing, steel framing, concrete framing, reinforced concrete framing and unreinforced concrete framing. These framed structure further classified into 36 different structural classes based on their structural design and material used. The detail of this building classification is given in the Annexure 9. Figure 3.3 shows the flow chart of HAZUS methodology for ERA of model building type. The methodology is divided into the seven steps. In the first step, input requirement are shown. The second and third steps shows the parameters required to generate the response curve and capacity curve respectively. The output from second and third steps is peak building response. It is calculated from the intersection of these two curves. The output of fourth step is used to calculate the cumulative probabilities of model building type, shown in step 5. The sixth step shows the calculation of discrete probabilities for all four damage states and finally the damage matrix is developed in step7.

Flowchart of HAZUS methodology

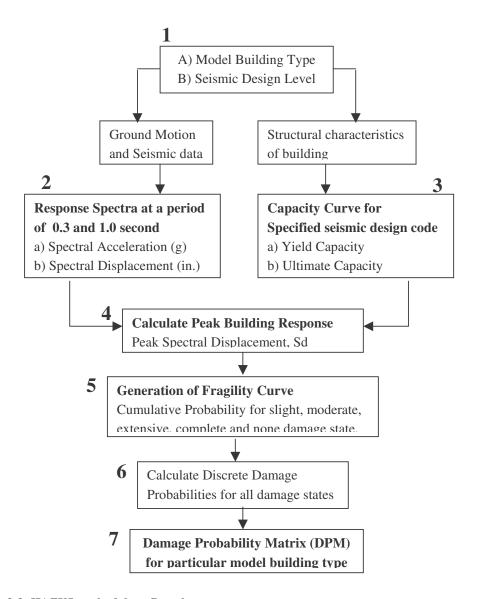


Figure 3-3: HAZUS methodology flow chart

The algorithm of calculating damage probabilities of model building type is described below. The damage algorithm can be summarized in seven basic steps.

Step 1: Select model-building type including height and seismic design level.

Step 2: Generation of response spectra

The demand spectrum is a plot of spectral acceleration, which is function of spectral displacement Spectral response at a period of 0.3 seconds and spectral response at a period of 1.0 second was considered to characterize the ground motion demand.

Parameters for Response Curve:

- 1) Soil Class
- 2) Spectral acceleration, S_A [0.3 second]
- 3) Spectral acceleration, S_A [1.0 second]
- 4) Soil Amplification Factor for given spectral acceleration
- 5) Spectral Displacement (using eq. $S_D = 9.8 * S_A * T^2$)

Where

 S_A = Amplified Spectral Acceleration (g)

T = Time Period (sec)

 S_D = Spectral Displacement (inches)

Step 3: Generation of capacity curve

The capacity curve represents the characteristics of a structure, which is a plot of lateral resistance of a building as a function of characteristics lateral displacement. The capacity curve is characterised by three controls points: design capacity, yield capacity, and ultimate capacity. In order to facilitate direct comparison with earthquake demand, the force (base shear) axis is converted to spectral acceleration and the displacement axis is converted to spectral displacement (NIBS, 2002).

Parameters for Capacity Curve:

- 1) Yield Capacity Point (Dy, Ay)
- 2) Ultimate Capacity Point (Du, Au)

Step 4: Calculate peak building response [S_d = Peak Spectral Displacement (in.)]

The peak building response is taken from the interaction of the building capacity curve and demand curve of the PESH shaking demand at the building location. The peak building response, either spectral displacement or spectral acceleration at the point of interaction of the capacity curve and demand curve is PESH parameter used with fragility curve to estimate the damage state probabilities

Step 5: Calculate cumulative damage probabilities

- a) Find median value of spectral displacement (\hat{S}_d) for damage state, design code and model type
- b) Find value of lognormal standard deviation (β) for damage state, design code and model type.
- c) Calculate cumulative probabilities for given damage state, ds P [S| S d], P [M| S d], P [E| S d], P [C| S d], using equation 5.1

$$P[ds \mid S_d] = \Phi \left[\frac{1}{\beta_{ds}} \ln \left(\frac{S_d}{\overline{S}_{d,ds}} \right) \right]$$
5.1

where:

 $P[S \mid S_d]$ = probability of being in or exceeding a slight damage state, S.

 $P[M \mid S_d]$ = probability of being in or exceeding a moderate damage state, M.

 $P[E \mid S_d]$ = probability of being in or exceeding an extensive damage state, E.

 $P[C \mid S_d]$ = probability of being in or exceeding a complete damage state, C.

S_d = given peak spectral displacement (inches)

 $\hat{S}^*_{d,ds}$ = median value of S_D at which the building reaches the threshold of damage state, ds.

 β^*_{ds} = Lognormal standard deviation of spectral displacement of damage state, ds

 Φ^* = Standard normal cumulative distribution function

Step 6: Calculate the discrete damage probabilities

Probability of complete damage, $P[C] = P[C \mid S_d]$

Probability of extensive damage, $P[E] = P[E \mid S_d] - P[C \mid S_d]$

Probability of moderate damage, $P[M] = P[M \mid S_d] - P[E \mid S_d]$

Probability of slight damage, $P[S] = P[S \mid S_d] - P[M \mid S_d]$

Probability of no damage, P [None] = $1 - P [S | S_d]$

Step 7: Develop Damage Probability Matrix (DPM) for model class.

Damage Probability Matrix						
Model type Slight Moderate Extensive Complete						
Probability P[S] P[M] P[E] P[C]						

Table 3:1 – Example of Damage Probability Matrix (DPM)

The HAZUS methodology uses the non-linear analysis method. It provides the most accurate and reliable risk assessment at the expense of detailed site, structural, material information and a higher level of technical expertise. This method considers the non-linear inelastic behaviour of structural members. This method can predict the non-linear behaviour of the structural system much more realistically for load and displacement levels ranging from linear domain through ultimate collapse (Buyukozturk and Gunes).

The vulnerability function in HAZUS is based on two types of curves known as capacity curve and demand curve. The demand curve is also known as a response spectrum, which is 5%, damped PESH (Potential Earth Science Hazard). The demand spectrum is a plot of spectral acceleration, which is function of spectral displacement (NIBS, 2002).

Figure 3-4 shows the typical shape of the response curve at 5 % damping. The response curve is divided into three regions such as region of constant acceleration, region of constant spectral velocity and region of constant spectral displacement. The region of constant spectral acceleration is defined by spectral acceleration at a period of 0.3 second. The region of constant spectral velocity has spectral acceleration proportional to 1/T and is anchored to the spectral acceleration at a period of 1 second. The constant spectral displacement region has spectral acceleration proportional to $1/T^2$ and is anchored to spectral acceleration at the period $T_{\rm VD}$. The shape of the response curve depends upon soil condition, structural damping and depth of base of the structure.

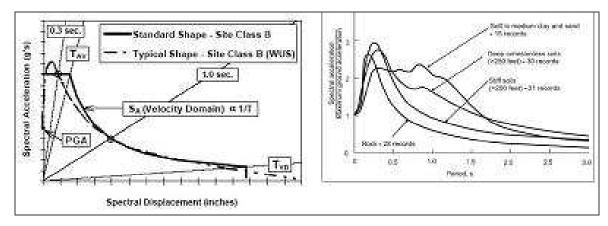


Figure 3-4: Example of typical response curve in HAZUS (left) and in India (right)

Source: (NIBS, 2002) ,left and source: (Jain, 2003), right

The building capacity curves are based on engineering design parameters and judgment and it is also known as a push-over curve (NIBS, 2002). The capacity curves are based on the non-linear elastic analysis method. The non-linear elastic method gives accurate estimation of building displacement response in the inelastic range. This cannot be accomplished using linear elastic analysis method. The capacity curves of each building are constructed with three control points, the design capacity, the yield capacity and ultimate capacity. The design capacity represents the nominal building strength. The yield capacity represents the true lateral strength and the ultimate capacity represents the maximum strength of building when global structural strength reached in full mechanism.

The capacity curve represents the characteristics of a structure, which is a plot of lateral resistance of a building as a function of characteristics lateral displacement. Figure 3.5 shows the typical roof displacement vs. base shear curve obtained from non-linear pushover analysis of buildings. In order to facilitate direct comparison with earthquake demand, the force (base shear) axis is converted to spectral acceleration and the displacement axis is converted to spectral displacement (NIBS, 2002).

Figure 3.5 provides an example capacity curve for reinforced concrete structures. The structure is considered to suffer no damage up to concrete cracking or design capacity. The crack size should be less than two millimetres and the damage is considered reparable up to yield point. Beyond yield point, the cracks are wider than two millimetres and the damage is considered irreparable. The repairs can be impractical and costly at ultimate capacity point.

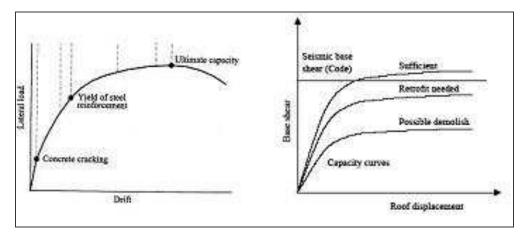


Figure 3-5: Typical example of capacity curve for reinforced building (left)

The peak building response is taken from the interaction of the building capacity curve and demand curve of the PESH shaking demand at the building location. The peak building response, either spectral displacement or spectral acceleration at the point of interaction of the capacity curve and demand curve is PESH parameter used with fragility curve to estimate the damage state probabilities. The figure 3-6 shows the schematic description of HAZUS methodology for ERA for building structures.

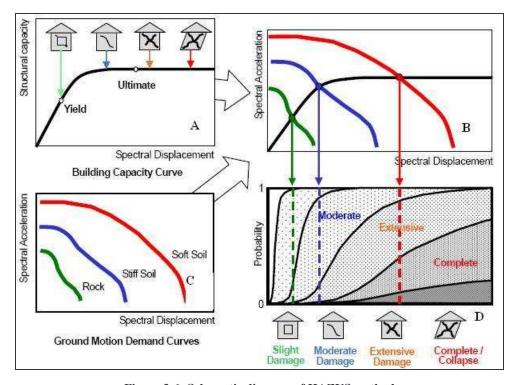


Figure 3-6: Schematic diagram of HAZUS method

Source: (Buyukozturk and Gunes)

The method divides damage states into four classes; namely slight, moderate, extensive and complete (appendix 6). The building elements are classified into three types naming structural elements, non-structural drift sensitive elements and non-structural acceleration sensitive elements. For each type of these elements, damage state has been classified and defined separately. HAZUS defined the different fragility curve for all the four damage stages for number of building. These fragility curves were developed in the form of lognormal probability distribution (NIBS, 2002). Each fragility curve is characterized by median value of spectral displacement (\hat{S}_d) and lognormal standard deviation (β). Median values of fragility curves are developed for each damage state and are based on building drift ratio that describes the threshold of damage state.

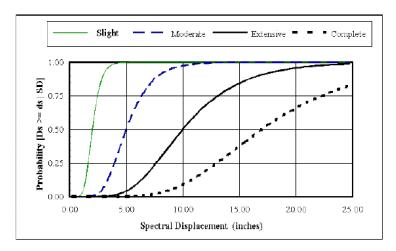


Figure 3-7: Typical example of fragility curve

Source: (NIBS, 2002)

The HAZUS methodology developed the damage functions by considering the four seismic design levels for each model building type such as high, moderate, low and pre code seismic design level. The seismic design levels represent the design and construction of the building. For example the high seismic design level represents the buildings are of modern design and construction. The low seismic design represents the buildings are of old design and construction. The seismic design level is defined by seismic zones of the Uniform Building code (UBC).

3.2.3. TELES Methodology

The National Science Council of Taiwan started HAZ-Taiwan project in 1998 to promote researches on seismic hazard analysis, structural damage assessment, and socio-economic loss estimation (Yeh, 2003). After gaining experiences on simulation of earthquake scenario for several years, the National Center for Research on Earthquake Engineering (NCREE), Taiwan developed application software in 2002 called Taiwan Earthquake Loss Estimation System (TELES), which follows a similar approach used in HAZUS for earthquake loss assessment. However, TELES has made major changes modifications in analysis models, parameters values and software architecture. The changes were made to accommodate the special environment and engineering practices in Taiwan. TELES have also added a feature of early seismic loss estimation to estimate automatically the disaster scale and its distribution soon after the occurrence of large earthquakes.

Figure 3-8 shows the methodology flow chart of TELES method of loss estimation. The TELES methodology can be roughly divided into four groups (Yeh, 2003), namely the potential earth science hazard, the direct physical damages, the indirect physical damages, and the socio-economic losses. In general, the civil infrastructures are classified into general building stocks, essential facilities, transportation and utility systems by their usage and functionality.

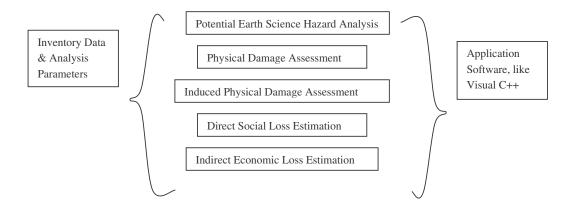


Figure 3-8 Framework of methodology in HAZ-Tai

TELES evaluate the damage state probabilities for each model building type and seismic design level due to ground motion and liquefaction-induced settlement. The damages for structural system and nonstructural components of building structures are evaluate separately in damage assessment. The capacity and fragility curves for each model building type and seismic design level are determined by reference to seismic design codes in various periods. The nonlinear pushover analysis and historical data collected after Chi-Chi earthquake.

An object oriented programming (OOP) language; Visual C++ is used to develop the application software, TELES. The other language used is MapBasic to communicate with MapInfo. Through the object linking and embedding (OLE) technology, the TELES integrate functionalities and custom usages of MapInfo, which is famous application software of geographical information system (GIS). The main functions of MapInfo in TELES are to view and to edit records and map objects in various kinds of database. All the numerical analysis is written in C++ and FORTRAN. The software architecture of TELES has module design, so addition and modification of individual module will not affect the other modules. TELES allows users to open multiple documents and multiple map windows at the same time, so the users can compare different thematic maps and obtain in-depth understanding of the relationships between input and output database. TELES allows users to monitor the earthquake occurrence and run scenario simulation in separate application windows at the same time, so the users will not miss any message sent from the Central Weather Bureau.

3.3. Earthquake risk assessment in India

For a country like India, with a variety of building practices and social and economic structures, seismic hazard and risk evaluation strategies need more emphasis for their development. Earthquake hazard of India is being monitored mainly by Geological Survey of India (GSI) and the India

Meteorological Department (IMD). The first national seismic hazard map of India was compiled by GSI in 1935. In 1962, India Standards Institution (ISI) published a second national seismic hazard map (BMTPC, 1999).

In 1997, the Ministry of Urban Development of the Government of India published the first Vulnerability Atlas of India (Dunbar et al., 2003). This atlas provides hazard maps for the most occurring natural hazards such as earthquakes, cyclones, and floods. Maps for all of India and for each State and Union Territory are included. The latest achievement in the development of risk mitigation and risk assessment is the revision in the Indian seismic code IS 1893 (Jain, 2003). This revision is made after a long gap of 18 years in 2002. As compared to the previous version, several major modifications have been incorporated in the new code (BIS, 1982). A macro-level map has already been prepared, which divides the country into four hazard zones, V to II, of various probable maximum intensities on a decreasing scale (Shukla, 2004). For all engineering design purposes, the earthquake hazard has been quantified in terms of MM (or MSK) intensities.

In India a number of organizations are involved in formulation of models and formulas for seismic risk assessment. Research education and training in earthquake engineering were started by the University of Roorkee (UOR) through the School of Research and Training in Earthquake Engineering (SRTEE) in 1960. Through this initiative, a national capacity has been built for design and construction of earthquake resistant structures from small to tall buildings and also other type of constructions (Arya, 2002). At present a number of institutions and organizations are engaged in such studies e.g. National Information Centre for Earthquake Engineering (NICEE) IIT-Kanpur, Earthquake Engineering Department IIT-Roorkee, Structural Engineering Research Centre (SERC) of Chennai, Building Materials and Technology Promotion Council (BMTPC) of Delhi, Central Building Research Institute (CBRI) of Roorkee etc.

The recent development in ERA was the Seismic Hazard and Risk Microzonation (SHRM) project. This is the first National level project in India, which involves the systematic multi disciplinary and multi institutional study on risk evaluation (DST, 2004). The study on SHRM was taken at Jabalpur, Madhya Pradesh in 2004. The project was taken at the instance of Department of Science and Technology (DST), Government of India (GOI) to evolve a model for seismic risk evaluation in India. The study was multi-institutional and involved Geological Survey of India (GSI), Indian Metrological Department (IMD), Central Building Research institute (CBRI), National Geophysical Research Institute (NGRI).

3.3.1. Seismic Hazard & Risk Microzonation (SHRM)

The SHRM model divided the risk evaluation process into five main components mainly a) source characterization b) characterization of wave path model c) Ground Characterization d) vulnerability analysis and e) Prognosis of loss and risk evaluation (DST, 2004). The first three components are worked under hazard assessment process.

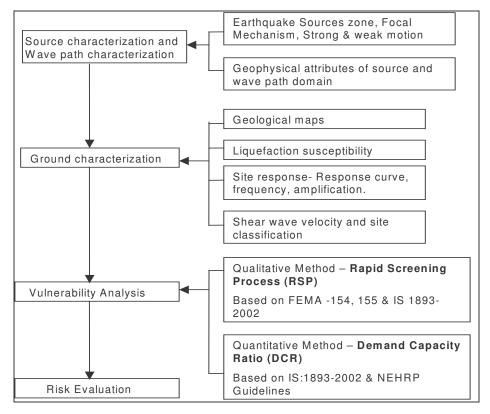


Figure 3-9: Flow chart of SHRM method for seismic microzonation

Source: (DST, 2004)

The figure 3-9 represents the schematic flowchart of SHRM methodology for risk assessment of building structures in Jabalpur city. The seismic evaluation leading to seismic vulnerability of existing building structures has been estimated by two approaches namely Rapid screening Process (RSP) (ATC 21, 1988) and Demand capacity Ratio (DCR) (ATC 40, 1996). The RSP is a qualitative approach and DCR is a quantitative approach. The sample survey was carried out for about 474 buildings spread over 62 zones of Jabalpur urban area including 22 surrounding villages (Agrawal, 2004). The methodology for vulnerability assessment of existing building structures is followed by four main steps namely building classification, survey of built environment, qualitative and quantitative vulnerability analysis and last step includes the analysis of vulnerable structures in two levels.

Building Type	Description
A	Building in field-stone, rural structures, un-burnt brick
	house, clay houses.
В	Ordinary brick building, building of the large block and
	prefabricated type, half-timbered structures, building in
	natural hewn stone.
С	Reinforced building, well built wooden structures.
X	Other types not covered in A, B.C

Table 3:2: Building classification used in SHRM project

Source: (Agrawal, 2004)

Table 3.2 gives the building classification used in SHRM project for seismic microzonation in Jabalpur. The buildings are classified into four major classes based on the construction material used and characteristics of roof and wall. The three major classes were considered for loss evaluation. These are RCC buildings, masonry buildings and buildings in field stone or un-burnt bricks

3.3.2. Rapid Screening Process (RSP) for all types of structures

The RSP is aimed to identify potentially hazardous buildings, without going into detailed analysis. RSP utilizes a methodology based on visual inspection of a building and noting the structural configuration (Agrawal, 2004).

The SHRM method is based on the Applied Technology Council's, ATC-21 (ATC 1988), method to predict loss as a percentage of the building replacement cost. The building type and effective peak acceleration are the two factors considered for damage calculation of the building. These factors will give the Basic Structural Hazard (BSH) score, which ranges from 1.0 to 8.5. The next considerations are Performance Modifiers, which range from -2.5 to +2.0, depending on whether they modify from the overall seismic performance of the building. Table 3.3 shows series of scores and modifiers based on building attributes. The methodology begins identifying the primary structural lateral load resisting system and material of the building.

Modifiers	Description	Modification Factor
High Rise	Up to 2 storey	0
	Between 3-7 storey	-0.20
	More than 7 storey	-0.50
Quality of	High	0
construction	Medium	-0.25
	Low	-0.50
Vertical Irregularity	Steps in elevation	-0.50
	Without Vertical	0
	Irregularity	
Soft Storey	Open on all sides	-0.50
	Building on stilts	-0.50
	Without soft storey	0
Plan Irregularity	"L", "U", "E", "T"	-0.50
	Without plan irregularity	0
Pounding	With pounding	-0.50
	Without pounding	0
Cladding	Large heavy cladding	-0.50
	No cladding	0
Soil Condition	Rocks (SR)	0
	Cohesion less soil (SC)	-0.30
	Black cotton soil (BC)	-0.60
Slope Ambience	Gentle	-0.10
	Moderate	-0.20
	Steep	-0.30

Table 3:3: Parameters and modification factors used in SHRM project

Source: (Agrawal, 2004)

The method generates a structural score 'S', which consists of a series of scores and modifiers based on building attributes. The structural score 'S' is related to probability of the building sustaining life threatening damage should a severe earthquake in the region. A low 'S' score suggests that the building is vulnerable and needs detailed analysis, whereas a high 'S' score indicates that the building is probably adequate. After detailed survey of representative buildings samples from each ward, individual buildings are categorized according to building types Type-A, B & C. Each building type is assigned with Basic Structural Hazard (BSH) score depending on earthquake forces it is likely to experience. This BSH reflects the estimated likelihood of a typical building of that category sustaining major damage given its seismic environment. ATC-21 and ATC-21-1 presents BSH for various building types applicable to state of California. These scores have been suitably modified in Indian context, based upon the 1997 Jabalpur earthquake damage survey data. These values have been determined so that a seismically good building has a high value, at a potentially weak/ hazardous building has a low value. The BSH scores used in the present study for type-A, Type-B and Type-C are 2.0, 2.5 and 3.0 respectively.

In order to arrive at final structural score 'S' for the building under review, a series of Performance Modification Factor (PMF) are subtracted from BSH. The number and variety of such PMF for all types of buildings is very large. However, based on experience gained during the damage survey in past earthquake, a limited number of the most significant factors were identified. These PMF were assigned values based on judgment such that when added/subtracted to BSH, the resulting modified score would approximate the possibility of major damage. If a building's structural score 'S' is less than 2, then the seismic performance of building may not meet the seismic criteria. Hence, such buildings are classified under vulnerable buildings.

3.3.3. Demand-Capacity Ratio (DCR) for Masonry and Reinforced Buildings

3.3.3.1. DCR for masonry buildings

DCR computation has been used for Type-B & C building and later it is related with the possible failure modes (DST, 2004). This approach is a comparison between some measures of demand that the earthquake places on a structure to a measure of capacity of the building to resist. All building components under evaluation should be able to resist the effect of the seismic forces prescribed in IS-1893-2002. The seismic base shear (V_B) calculated as per codal provisions is the basic seismic demand placed on the structure for seismic ground motion in a particular zone.

3.3.3.2. DCR for RC framed buildings

In order to critically evaluate the RC framed buildings, collected data of building samples are to be modelled using sophisticated structural analysis software under combination of loading for computing the end forces in each structural members. Apart from the dead and live loads, buildings shall be evaluated to the design basis earthquake (DBE) loads, the earthquake which can reasonably be expected to occur at least once during the lifetime of the structures. Model analysis based on response spectrum method has been adopted to dynamically analyse the building. The analysis directly computes member end forces and then each member is designed foe worst load combination. The design module of analysis engine gives the longitudinal and transverse reinforcement for each member. This reinforcement provided in a particular member would correspond to capacity. In order

to calculate the DCR, the calculated reinforcement of structural members has been compared with provided reinforcement. The DCR for longitudinal and transverse reinforcement reflects DCR for flexure and shear of member. The DCR calculated for flexure and shear gives the idea about inherent ductility and strength of member to ensure safety and serviceability during severe shocks. The DCR greater than one for flexure indicates that the longitudinal reinforcement in columns and beams are inadequate leading to failure. The possibility of failure of such is excessive cracking leading to collapse. Whereas DCR greater than one in shear indicates that the lateral ties provided are not sufficient leading to brittle failures.

3.3.4. Prognostic Damage Evaluation

In order to present the prognostic damage scenario using quantitative approach, the failure modes of different building classes are collated. Table 3.4 shows the prognostic damage scenario of three building types in Jabalpur.

Damage Mode	Damage	Damage Mode	Damage
Type-B	Scenario Type-B	Type-C	Scenario Type-C
EC	15 %	EC	0 %
FW	0 %	DC	0 %
FH	29 %	FH	34 %
EC+FW	2 %	EC+DC	9 %
EC+FH	36 %	EC+FH	7 %
FW+FH	1 %	DC+FH	7 %
EC+FW+FH	1 %	EC+DC+FH	32 %
Safe buildings	16 %	Safe buildings	11 %

Table 3:4: Prognostic damage scenario for building in Jabalpur, India

Source: (DST, 2004)

The prognostic damage scenario of Type-B, the failure modes have been categorized as excessive cracking (EC), falling of wall (FW), falling hazard of non-structural members (FH) and combination of these three failure modes. Similarly, the various failure modes for assessing seismic vulnerability of Type-C buildings are identified as excessive cracking (EC), diagonal cracking (DC), falling hazard of non-structural members (FH) and combination thereof and safe buildings. The methodology includes gross evaluation of earthquake hazard, seismic vulnerability of built environment and anticipated loss due to earthquake hazard.

3.4. Previous work in earthquake risk assessment in India

The number of initiative has been taken by government and non-government agencies in India to reduce the impact of earthquakes in urban areas. The study has been done by non-government agencies such as Risk Management Solution of India (RMSI), GIS development, etc. in various parts of the country. The government agencies, which are involved in ERA process, are CBRI, GSI, DEQ-UoR, IMD, and NICREE. The main cities where the study has been carried out for earthquake reduction are Bhuj (Gujarat), Chamoli (Uttaranchal), Jabalpur (Madhya Pradesh), and Delhi. The study of ERA has been carried out by RMSI in Bhuj. The detail of this study was not available to the researcher. The

seismic microzonation studies carried out by CBRI in Delhi, Jabalpur and Dehradun (Agrawal and Ajay, 2004). The seismic evaluation was done by using two techniques such as quantitative assessment with demand capacity approach and qualitatively with rapid screening process approach. The study adopted the same methodology as described in the section 3.3 of chapter 3. The study concludes that the results of seismic microzonation process is largely depends upon the accuracy of spatial database. The study stressed on the capabilities of GIS tools in collating and integration of theme based data for seismic vulnerability of buildings. The joint study by NSET and DEQ-UoR was carried out in 2000 for damage assessment in Chamoli of Chamoli earthquake (M6.8, 1999) (NSET, 2000). The extensive field survey was done to collect the building damage information. The study lacks the involvement of any advance technology such as remote sensing to detect the damage. The ERA study in Chamoli concludes the weak construction and poor construction technology was the main cause of damage to buildings. The report shows the 98% of the buildings were owner built in study area, Chamoli.

The earthquake risk assessment of the HAZUS methodology has been used in many countries outside United States such as Istanbul, (Turkey), Newcastle (Australia), Taiwan, Bhuj (India). The HAZUS methodology was applied by Chiroiu (Chiroiu et al., 2002) in Bhuj, Gujarat (India) in order to estimate human causalities from 2001 Bhuj earthquake (M7.7). The unreinforced masonry (URM) from HAZUS building classification was considered, as most representative building type exists in that area for damage assessment. This methodology was than compared with simple statistical approach applied, based on various statistics and engineering judgments. The causality evaluation from HAZUS based approach is considerably lower than the output of the second simplified approach (Chiroiu et al., 2002) The results came from HAZUS based approach were substantially underestimated. The number of deaths due to earthquake was estimated around 50 times lowers than the official's statistics.

The limitations regarding assigning the damage state in post earthquake assessment were observed by Basoz and Kiremidjian (1997) during January 17, 1994 Northridge, CA earthquake. They observed that there is often a discrepancy between the damage levels that any two inspectors would assign during post earthquake damage assessment. The other limitation observed was in generation of fragility curve to get an adequate number of buildings belonging to one building class that lie in a particular damage state (Neilson, 2003). Thus it is often required to group classes together to get enough buildings in a given damage state and hence reduces the usefulness of the fragility curve.

3.5. Conclusion

After a review of the various approaches towards earthquake risk assessment we come to the conclusion that loss estimation models are only as good as the information that is put into it. In this study the stress was given to collect the material related to vulnerability assessment of built up structures for seismic evaluation. The study explains the qualitative and quantitative methods of estimation of seismic vulnerability of existing building stock.

RADIUS method gives preliminary loss estimation of earthquake. This method is very simple and it uses the common building types for building classifications. Therefore it is very easy to implement this methodology in developing countries. The drawback of this methodology is that is not possible to identify the vulnerable area. The methodology only gives the result in the form of percentage of

building damage. The quantification of damage is also not possible by using this methodology. This methodology does not considered the complex structural aspect of the building vulnerability.

The methodology developed by NIBS is very comprehensive in terms of the modelling of urban earthquake risk. The building classification was made on the basis of the building material and construction technique used in United States. The classification of buildings system covers most of the building types for developed countries. This same approach was used in assessing causality loss of Bhuj earthquake in India (Chiroiu, 2003). The losses and causalities were estimated fast using the characteristics of un-reinforced masonry (URM) buildings. The building type considered in this study was common in Bhuj region and fragility curves were taken from HAZUS methodology. The HAZUS approach nonetheless relies heavily on undocumented engineering judgment. The HAZUS methodology uses non-linear analysis method for doing vulnerability assessment and generating fragility curves which is based upon the complex structural equations and calculations. The occupancy classification used in the HAZUS methodology does not match with the occupancy classification defined in the National Building Code, India. The attenuation functions (WUS and CEUS) used in HAZUS method are not applicable in Indian context due to difference in soil classification. Most of the other methods used MMI, which is derived from PGA for vulnerability assessment of building structures. However, merely determining the spatial variation of peak ground acceleration is not adequate, because peak acceleration often correspond to high frequencies, which are out of range of the natural frequencies of most structures (Slob et al., 2002). The HAZUS method uses the spectral displacement (S_D) of structural and non-structural elements of a building to ground motion for building vulnerability assessment

The Indian model for seismic risk evaluation integrates multi thematic data for hazard assessment and vulnerability analysis. The data includes ground characteristics, geotechnical attributes and engineering seismological attributes of the built environment. The qualitative approach, RSP estimates structural scores based on national and international state-of-art procedures. RSP helps in developing a list of potentially hazardous buildings without a high cost of detailed analysis of every building. DCR covers demand-capacity computation, which evaluates the measure of capacity of the building to resist in the seismic shocks. The DCR method uses the linear analysis method of risk evaluation. The linear method The DCR method requires lots of engineering inputs and assesses the vulnerability of building by considering every structural member of the structure. It requires an involvement of expert for analysing the structural behaviour of members.

The risk evaluation process in Indian condition can be categorized into two major groups namely preliminary estimation and detailed estimation. To carry out the detailed risk estimation process under Indian condition availability of data is one of the critical components. The data required is not sufficient to carry out detailed estimation and is not readily available for security considerations. The HAZUS multi hazard loss estimation methodology is considered for this research for evaluating earthquake loss for building structures in study area. The HAZUS methodology will be used with available dataset and number of assumptions will be made to analysis the results. The overview of study area and data preparation will be discussed in next two chapters.

4. Study area

This chapter gives an overview of the study area – Dehradun city. It also gives a general idea about its geographical location, area and its susceptibility for seismic events in the future. It also addresses the functioning of the city, characteristics of built form and settlement structure of the city. The social economic profile and demographic characteristics of the city are also taken into consideration

4.1. Introduction

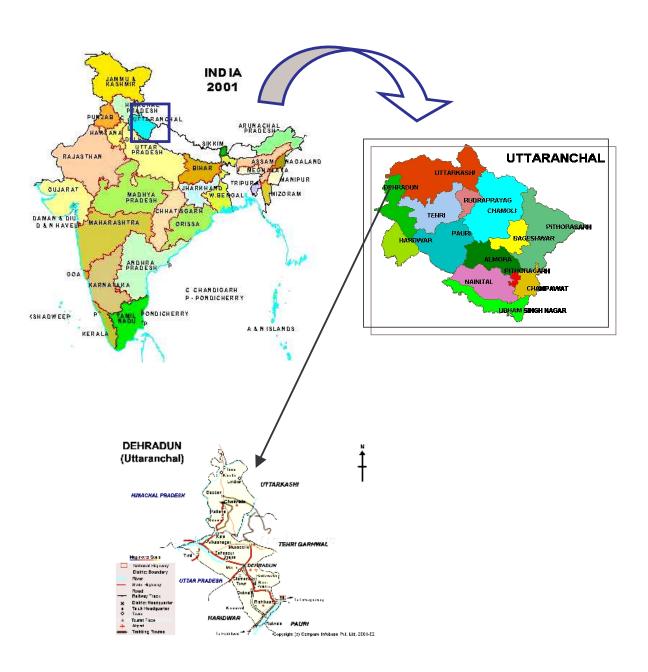
The city of Dehradun is the interim capital of Uttaranchal since the year 2000. It is situated in North India and is the largest city in the northwestern part of the Uttaranchal state. The name Dehradun is literally made up of two words where *Dera* means Camp and *Dun* stands for Valley. Dehradun is a longitudinal valley and situated in the foothills of Himalayas at the centre of the 120 kms long Doon Valley. Dun or Dhoon in Sanskrit and Hindi respectively mean an elongated valley. The city is the gateway to Gharwal sub-region and Queen of Hills – Mussorie of Uttaranchal state. It is well connected with Delhi, Saharanpur, Hardwar, Lucknow, Chakrata and Massourie by rail and road network. Besides, it is an educational center with some of the best schools and academic institutes in the country located in the city.

4.2. Geographical Location and Area

Dehradun lies between 30° 15' 58" N to 30° 24' 16" N latitude and 78° 06' 05" E to 77° 58' 56" E longitude. The administrative control of the Dehradun Municipal Board (DMB) is 65.85 sq. kilometers in area. The DMB area was divided into 34 wards according to the 1991 provincial data. In 1995, at the time of municipal election, the number of wards was reduced to 33 only. Recently in 2003 during the preparation of the voting list for municipal election, the wards were again revised and increased to 45 in number. The physical limit of Dehradun municipality is marked by two intermittent streams namely Rispana River in the eastern part and Bindal River in the western part. Dehradun city is located on a gentle undulating plateau at an average altitude of 640 m. above mean sea level. The lowest altitude is 600 m. AMSL in the southern part, whereas the highest altitude is 1000m AMSL on the northern part. Figure 4.1 shows the location of Dehradun in map of India.

Figure 4-1: Location of Dehradun in map of India

Source: www.mapofindia.com



4.3. Susceptibility for Earthquakes

Uttaranchal is situated in the foothills of the Himalayas, which is highly susceptible to earthquakes (MHA, 2003). The Main Boundary Thrust (MBT) and the Main Frontal Thrust (MFT) are the main active features in Uttaranchal, thus have the greatest potential for a future great earthquake (M >7.5) at any time (Sharma, 2003b). Garhwal Himalayas has experienced quite strong earthquakes like Uttarkashi earthquake (M 6.6) in 1991 and Chamoli earthquake (M 6.8) in 1999. Dehradun city lies in the seismic zone IV (Jain, 2003). Dehradun Municipal Corporation (DMC) has a population of about 0.5 million in 2001 (GOI, 2001b). The Kangra earthquake of 1905 had rupture zone extended up to near Dehradun city and there are records of damage at several parts of Dehradun city. Table 4.1 gives the list of earthquakes in Himalayan region.

Date	Intensity	Place
1 September 1830	9.0	Badrinath
26 May 1816	7.0	Gharwal
25 July 1869	6.0	Nainital
28 October 1916	7.5	Dharchula
28 October 1937	8.0	Dehradun
27 July 1966	6.3	Dharchula
28 August 1968	7.0	Dharchula
29 July 1980	6.5	Dharchula
20 October 1991	6.6	Uttranchal
29 March 1999	6.8	Chamoli

Table 4:1: List of earthquakes in Himalayan region

Source: (Shukla, 2004)

The Dehradun city has short listed by UNDP as one of the most earthquake prone city in the country (BMTPC, 2003). The city ranked first among the 38 cities with over half a million population and lies in seismic zones III and IV (Arya, 1999).

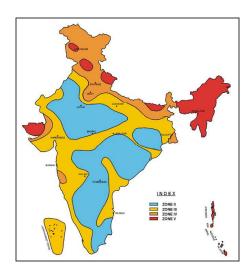


Figure 4-2: Seismic zonation map of India

Source: (Shukla, 2004)

This region has already faced 36 major earthquakes in the last one and a half century. During the last century, the region has had 12 earthquakes of magnitude greater than 6.0—on the Richter Scale (Singh, 2005b) Table 3-5 above provides details about the earthquakes in the Uttranchal Himalayas

4.4. Climatic conditions

In general the climatic conditions of the study area are subtropical to temperate. Dehradun experiences four seasons, namely, winter, summer, rainy and post monsoon seasons. The period from November to February is the winter season. The summer season following continues up to the end of June. The rainy season is from July to about third week of September followed by post monsoon or transition period till the middle of November. The maximum average temperature is $36^{\circ}\text{C} \pm 6^{\circ}\text{C}$ and the minimum average temperature is $5^{\circ}\text{C} \pm 2^{\circ}\text{C}$. In summers the maximum temperature i.e. $36 \pm 6^{\circ}\text{C}$ and the minimum temperature is $16 \pm 7^{\circ}\text{C}$ whereas in winters it varies from $23 \pm 4^{\circ}\text{C}$ and $5 \pm 2^{\circ}\text{C}$ respectively. The average annual rainfall of Dehradun City is 2183.5 millimetres. About 87% of the rainfall is through monsoon and is received during the months from June to September, July and August being the rainiest months. The relative humidity is high during the monsoon season normally exceeding 70% on an average.

4.5. Landuse Pattern

The landuse pattern for Dehardun has evolved on the basis of mixed landuse zoning particularly in the central area and built-up areas of the city. The mixed landuse zoning in the central part of the city maximize the use of services and minimize the movement. Decentralize of work centers and transportation facilities have minimized the dislocation of present landuse pattern.

Table 4.2 gives the existing and proposed landuse pattern in Dehradun city in 1981 and 2001

SN	Landuse Pattern	Existing	Existing	Proposed	Proposed
		Area	Area	Area	Area
		(Ha) 1981	(%) 1981	(Ha) 2001	(%) 2001
1	Residential	1588.8	41.78	3001.77	42.6
2	Commercial	81.0	2.14	290.0	4.12
3	Industrial	113.36	2.98	350.0	4.97
4	Public & Semi public	802.22	21.0	833.21	11.82
5	Govt. & Semi Govt	267.20	7.0	313.52	4.45
	offices				
6	Parks, open space & recreational area	156.00	4.10	226.0	3.22
7	Orchards & Gardens	205.65	5.4	250.65	3.55
8	Circulation (roads)	203.03	5.35	400.09	5.68
9	Water bodies	331.5	8.74	129588	18.39
10	Undefined uses	55.0	1.45	84.01	1.20
	Total	3802.75	100	7045.13	1.20

Table 4:2: Landuse patteren in Dehradun in 1981 and 2001

Source: (MDDA, 2001)

Table 4.3 gives the existing and proposed landuse pattern in Dehradun city in 2001 and 2025

S	Landuse Pattern	Existing	Existing	Proposed	Proposed
N		Area	Area	Area	Area
		(Ha) 2001	(%) 2001	(Ha) 2025	(%) 2025
1	Residential	2989.3	8.33	5325.65	14.84
2	Commercial	298.52	0.832	423.32	1.18
3	Industrial	40.50	0.113	331.67	0.52
4	Govt. & Semi Govt	470.59	1.312	925.97	2.58
	offices				
5	Utilities and services	289.02	2.979	1030.49	2.88
6	Public & Semi public	NA	NA	132.92	0.37
7	Tourism and recreation	NA	NA	202.16	0.56
8	Parks and open space	NA	NA	978.88	2.73
9	Transport and	425.1	1.186	1517.80	4.23
	circulation				
10	Miscellaneous	NA	NA	24998.34	69.71
	Total	9686.87	27.04	35867.2	100

Table 4:3: Landuse patteren in Dehradun in 2001 and 2025

Source: (MDDA, 2005a)

4.6. Settlement pattern and urban form

The Eastern Rajpur canal was the most important feature in Dehradun during British government period. This canal was the only source of drinking water for inhabitants and also served for

agricultural requirements. The Central part consists of the old city and the private residential areas. The prestigious educational and research institutions are situated outside the core city. The western side houses the cantonment, Oil and Natural Gas Corporation, Forest Research Institute and Wadia Institute of Himalayan Geology. The eastern part of the city is largely residential. The city has radial type of road network. The city is divided by six major roads radiating from the center of to the regional area.

4.7. Building Character

Figure 4.3 presents the building material used for construction in Dehradun. The principal building system practiced in the urban areas of the city consist of framed structure built up of RCC columns and beams as structural elements with infill masonry wall. The other building system exists in the urban city consists of load bearing structure with unreinforced infill masonry wall. This system is used in old buildings of the city and limited to small section of the total built up area of urban settlement. The predominant building material used in the urban city consists of masonry wall with burnt brick as construction material. The percentage of burnt brick uses for wall construction is 60 percent (Census 2001). The other building materials used for wall construction are stone, wood, concrete, mud, asbestos sheet and thatch. The construction material generally in practice for roof materials is reinforced cement concrete (RCC). The percentage of RCC uses for roof construction is 85 percent. The other major roof materials used in city are corrugated G.I sheets, asbestos sheet, slates, tiles and brick.

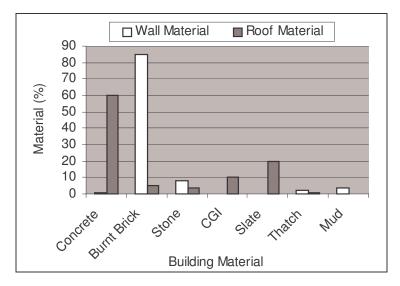


Figure 4-3: Building materials used for construction in Dehradun

Source: (GOI, 2001b)

Construction Material	Concrete %	Burnt Brick %	Stone %	CGI %	Slate %	Thatch %	Mud %
Wall Construction	1	85	8	0	0	2	4
Roof Construction	60	5	4	10	20	1	4

Table 4:4: Percentage of building material used in Dehradun

4.8. Road Network

The existing circulation pattern of Dehradun city is of the radial type. There are six major roads radiating from the centre of the city to the regional areas. These radial corridors serve for intercity traffic. The city does not have any other system, which can supplement the road network system. Though the railway terminates in the city, it serves only inter-city traffic and does not share the burden of roads for local traffic. The road network does not have any defined hierarchy. The cross sectional elements of the roads frequently change their values. Consequently roads have frequent bottlenecks and have not continued to function homogenously. The Dehradun Municipal Corporation maintains 305.14 Km of road network in the city. The majority of intermediate roads are narrow and smaller in width, ranging between 6.0 to 8.0 m. The Dehradun Master Plan defines the major roads width ranges from 30 to 35 meters but the permanent as well as temporary encroachments have reduced the carriageway width to merely 15 to 25 meters.

4.9. Demographic character

4.9.1. Population distribution and size

Uttaranchal is one of the largest states in India and has population of 8 million approximately. The state is divided into 12 districts and Dehradun district has the largest population among these districts. Dehradun district has a population of 1,282,143 according to census 2001. The Dehradun district is again sub divided into four sub districts namely Chakrata, Vikasnagar, Dehradun and Rishikesh. The Dehradun sub district lies at the center of Dehradun district and has a highest population among all sub districts of about 0.74 million. The Dehradun sub district again sub divided into 8 towns namely Clement town, Dehradun, Dehradun Municipal Corporation (DMC), Daiwala, Forest Research Institute, Landaur, Mussaurie and Raipur. The DMC has the highest population among all towns in Dehradun sub district. The DMC town has a population of 0.447 millions. It has 84012 numbers of households and household size is 5.1. The DMC has 43 numbers of wards and is 65.85 sq. kilometers in area.

4.9.2. Population Growth

Figure 4.4 shows the decadal growth of population in Dehradun. As per 1991 census, the population of DMC was 270159, which has increased to 426674 in 2001. The population has increased exponentially in this decade by 65.76 percent. The population of Dehradun was 2,100 in 1817. During 1981-91, its population has increased from 2,11,838 to 2,70,159. The growth at this rate would increase the population of Dehradun Municipal Board to 4,20,271 by the year 2011. Table 4.5 shows the absolute figures of population, increase of population and the percentage increase for each decade from 1901-2001 for Dehradun Municipal Area.

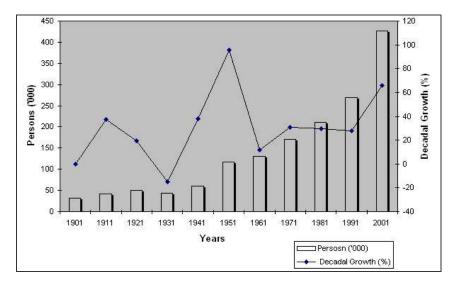


Figure 4-4: Decadal Population growth in Dehradun

Source: (GOI, 2001b)

Yea	190	191	192	193	194	195	196	197	198	199	200
r	1	1	1	1	1	1	1	1	1	1	1
Population ('000)	30	42	50	43	59	116	129	169	211	270	447
Decadal Growth (%)	-	37	19	-15	37	95	11	30	29	27	65

Table 4:5: Decadal growth of population in Dehradun

Source: (GOI, 2001b)

4.9.3. Household size

The household size related to the number of habitable rooms gives an idea about occupancy ratios and the degree of congestion. It is helpful in estimating future housing requirements of the city. According to the 1971 census the population of Dehradun Municipal Area was 1,69,000 persons with 33,339 households, therefore, the household size 5 persons. In 1981 and 1991, though the number of households has increased, the household size remained same. According to 2001 census the population of Dehradun Municipal Area was 426,674 persons with 84,012 households and household size was 5.1 persons.

4.9.4. Density pattern

A study of density enables us to understand various aspects such as intensity of the use of urban land, problem of overcrowding arising out of congestion and high occupancy rate, adequacy and inadequacy of open space etc. Gross density within Dehradun municipal area was 7,109 persons per square kilometre according to 2001 census. Presently the average population density of Dehradun municipal area 133 persons par hectare.

4.9.5. Housing

Housing areas, which cover large portions of an urban settlement, influence the quality of urban life, which in turn attacks, the efficiency of the settlements. Most of the housing areas especially in the central core of the city have zigzag narrow roads which are difficult to be widened and there is a general lack of parks and open spaces. The relatively new housing areas along Hardwar Road, Mussoorie Road and Chakrata Road are in the form of developed colonies. The percentage of permanent and semi permanent housing structure in the urban area of the city is 91.8 and 5.7 respectively (Census 2001). The temporary housing structures in the urban area are near to 2.5 percent of the total housing structures in the city.

According to 1971 census figures, the total number of households within Dehradun Municipal area was 39473 and the number of occupied residential houses is 28732, which give a housing shortage of 11101 houses. There are 1.4 households per residential house, i.e. more than one family is living in one house, which implies high occupancy rate. On an average, there are 5 members/household. According to 1981 and 1991 census figures, the total number of households was 41519 and 53438 respectively and the number of occupied residential houses for '81 and '91 are 37260 and 52726, which gives a housing shortage of 4259 and 1322 respectively.

4.10. Local authorities in Dehradun

For planning, development and regulatory purpose, Dehradun has two main Urbal Local Bodies (ULB's). One is the Mussorie Dehradun Authority (MDDA) and the second is the Dehradun Municipal Corporation (DMC) (MDDA, 2005b). The MDDA was constituted in the year 1984 by the state Government of Uttar Pradesh (U.P) under the provisions of U.P. Urban Planning and Development (UPD) Act 1973. The main aim of the MDDA was to check the haphazard development and degradation of natural environment in the city. DMC is a local decision making agency and it is totally self-sufficient, capable of undertaking all sorts of activities for well planned urban development. The DMC was constituted with a aim of ascertaining a proper coordination with all the departments concerned for the development of the city. The DMC is responsible for provision of civic amenities and facilities in the areas within the 45 wards. Besides it also performs functions such as collection of taxes, etc. MDDA and DMC in association with Town and Country Planning Department (TCP) Uttaranchal have prepared a Master Plan 2021 with the objective to achieve planned growth of Dehradun.

4.11. Initiatives taken for earthquake vulnerability reduction

Numerous activities have been taken by the Government of Uttaranchal to stengthen the capabilities of earthquake vulnerability reductuion in Dehradun city. A number of National and International assessment and mitigation programme on earthquake is running in Dehradun city. The MDDA organized a two-day consultation on Urban Earthquake Vulnerability Reduction Project on the National Disaster Reduction Day, 29th October 2003. This consultation was organized in technical association with Disaster Management and Mitigation Centre (DMMC), GoUA (MDDA, 2003) with an objective to discuss earthquake vulnerability of Dehradun city. The aim of this consultation was to constitute a City Disaster Management Committee (DMC) to priorities activities and identification of task forces to carry out city specific activities. This initiative was an important component of the

overall GOI-UNDP Disaster Risk Management Programme being initiated in Uttaranchal by the State Government.

Asia Disaster Preparedness Center (ADPC), in association with the World Institute for Disaster Risk Management (DRM), Virginia, USA and Centre for Development Studies (CDS), Nainital, India has been engaged by the Asian Development Bank (ADB) to undertake a Technical Assistance (TA) project for the states of Uttar Pradesh and Uttaranchal in India (www.adpc.org). The main goal of this program is to reduce earthquake vulnerability, using seismic hazard mapping, procedures and manuals as well as developing and strengthening of Disaster Management Information Systems (DMIS) network communications and Geographic Information Systems (GIS).

4.12. Summary

The chapter provides the overview of Dehradun city in terms of its geographical location, area, and susceptibility for earthquakes, climatic conditions, landuse pattern, settlement pattern, building character, road network and demographic character. The various aspect of the city like landuse, settlement pattern, building character and density pattern will be considered for selecting the study ward. The selected ward should have a fair quantity of built-up structures to make the inventory of buildings for ERA. The settlement pattern should have majority of permanent structures. The building character of the ward should have building structures, which can be comparable with model building type of HAZUS building classification. The building density of ward should not be very high. The high building density makes the field survey of existing buildings more difficult and cumbersome. The overview would help in understanding the construction and demographic aspect of the city and also in selecting the study ward within the city.

5. Database Preparation

This chapter deals mainly with two main phases namely data collection and data preparation. It explains the method of collecting data from academic, government and semi government institutes and organizations. The database of sources of collecting information required for vulnerability assessment for building structures in the study area is also provided. The primary and secondary data collected and various problems in collecting data from the field are described. The preparation of questionnaires for the collecting building information is also discussed in this chapter. It describes also the various datasets used for data processing and database generation for the study area. The method of creating a building inventory for vulnerability assessment by various means is one of the major parts of discussion in this chapter as well.

Figure 5.1 shows the methodology flow chart of research. The methodology comprise of foue baisic steps. The first section gave a review of risk assessment methods in India and in other countries. The second section dealt with the identification and generation of the dataset (seismic, ground motion, building response and damage functions) required for using HAZUS methodology in a study area. The third section dealt with the possible modifications required to use HAZUS based building classifications in a study area in India. This also included the discussion with field experts of various institutes and organizations on the issue of using the HAZUS based building classes in the Indian context. The fourth section dealt with tested the HAZUS methodology for risk assessment of buildings in a study ward.

5.1. Data Collection

The first phase dealt with the collection of data required for vulnerability assessment methods for earthquakes practiced in India and data required for running the HAZUS model in the Indian context. This was done through the institutional survey after completing literature review for the research work. The number of institutions was short listed after discussion it with my IIRS supervisor. The concerned persons and officials in various institutes were approached through email and telephone prior to start the actual institution survey.

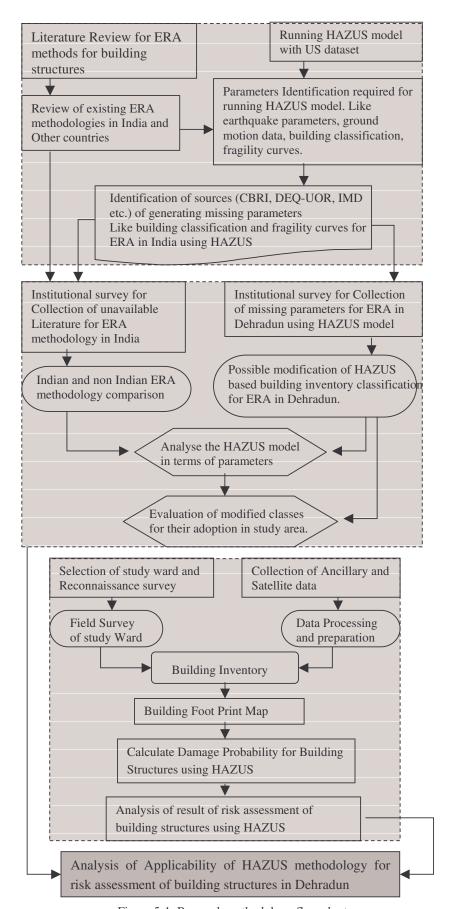


Figure 5-1: Research methodology flow chart

5.1.1. Institutional Survey

A number of organizations were visited during the institutional survey. A proper plan was prepared prior to the actual start of this survey. The total eight working days were allotted for this survey. The main objective of this survey was to find the sources from where the missing parameters such as building classification and building vulnerability curves can be generated and to see which information required for using HAZUS building classification in study area. This was done after studying literature available on internet, ITC library and IIRS library.

The HAZUS model was run prior to this survey for different earthquake scenarios with US data sets that comes along with the HAZUS software, to list out the needed, available and missing parameters, which had to be collected from various sources through the institutional survey. One of the major tasks under this survey was to collect and create a database for sources of information required for this research was one of the major tasks under this survey. A number of academic, government and semi government institutes and organisations in different states of the country were visited for collecting this information. The various organisations and institutes visited in this survey are given in the appendix 3.

The research project and objectives were discussed with faculty of academic institutes and officials of government organisations having the same research area. The reference and contact of other persons and institutes, which are working on this research area, was also collected from the above-mentioned faculty and officials. One of the major obstacles for collecting information from government organisations was the unwillingness of these officials to share the research work with academic institutions for security purposes. To take appointment for discussing an academic project with research related officials of these organisations was one of the most tedious jobs of this survey. The references taken from various faculties played a major role in collecting information from Govt. organisations. A number of scientific papers and research materials were collected from these organisations and from faculties of academic institutions. A few short listed organisations could not be visited due to unavailability of faculty at the time of this scheduled survey. These faculties were contacted later on through email and their research materials were collected via post. Some related research papers and research materials could not be collected from the visited institutes due to the unavailability of the published material and not sharing of unpublished data. Some of the unpublished data had been collected from these institutes but could not be used in this research due to the institutional policy.

The main issues, which were mainly discussed in this survey, were the risk assessment methods in India, adoption of HAZUS building classification in study area and availability of vulnerability curves for typical buildings types that exists in study area. The CBRI and DEQ-IITR were the two main institutions, where these two main issues were discussed in details. The HAZUS building classification was first discussed with Dr. Shailesh Agrawal, the Assistant Director of CBRI. Dr. Shailesh Agrawal had been involved in a SHRM project, which has been mentioned in the chapter 3 of this report, for vulnerability assessment of buildings in Jabalpur, Madhya Pradesh (Agrawal, 2004). The same issue was than discussed with Dr. Yogendra Singh, faculty member of DEQ-UOR. Dr. Yogendra Singh has been involved in a joint IITR - Norway project for assessing building vulnerability in Dehradun using inelastic analysis method of risk evaluation.

The discussion on adoption of HAZUS building classification included the difference in the structural properties of HAZUS model-building types with the structural properties of typical buildings exists in the study area. The discussion also included the modification needed in these classes to match it with construction practice in study ward. After discussing these model-building classes in details, the two model building types were selected for this study namely Reinforced Masonry Bearing Walls (URM) (NIBS, 2002). The structural properties of these two model classes were resembles with the structural characteristics of two most prevalent building structural systems exists in Dehradun, which are RCC framed structure and load bearing structure. The RM2 and URM were considered to be most representative model buildings for ERA in Dehradun using HAZUS methodology. The availability of building vulnerability curves for typical buildings in Dehradun was also discussed in these meetings. According to Dr. Yogendra Singh, the building vulnerability curves used by HAZUS methodology are not applicable for typical buildings exist in Dehradun. The vulnerability curves are entirely based on structural inputs of the buildings. It is very difficult to collect the structural information of buildings without any structural expertise.

The two most prevalent building structural system exists in the study ward are RCC framed structure and load bearing structure. The detailed descriptions of these model-building types are given in the annexure 6. However the structural properties of these model-building types do not resembles exactly with the structural properties of existing building structures in the ward.

The information about risk assessment method in India was collected from Earthquake Risk and Evaluation Centre (EREC) at Indian Meteorological Department (IMD,) Delhi. The discussion was carried out with Dr. PS Mishra, fellow member of Geological Survey of India. He had been involved in the earthquake hazard assessment of Jabapur city in SHRMproject. The discussion included the methodology used for risk assessment in SHRM project. The dataset used and general information about the project such as duration and cost of the project.

5.2. Data Preparation

The second phase dealt with the data collection for study ward in Dehradun city by field survey. A study ward was selected after discussion with IIRS supervisor and doing rapid survey of short listed wards. A fieldwork plan was prepared and list of parameters were framed prior to start actual fieldwork in selected ward. Already available data was referred for field survey and a data collection form based on ATC 21 was prepared after discussing with IIRS supervisor and CBRI officials.

5.2.1. Field Survey

The field survey was further broadly divided into two main sections namely preliminary survey and detailed survey. The preliminary survey was done after collecting the dataset from literature of previous studies of listed wards. The ancillary and satellite data was also collected prior to start of the survey. A second section of the field survey dealt with the selection of building samples of selected building types and structures existing in the study ward. It included the collection of missing building data from selected ward and preparation of data collection form for selected ward for vulnerability assessment on the basis of reconnaissance survey. The questionnaire was tested for two wards within

Dehardun and modifications were done thereafter to prepare the final questionnaire for data entry from the selected study ward.

5.2.2. Reconnaissance survey

The first section comprises of a reconnaissance survey of the city in which a number of wards were visited to get an overview of the building character of the built up structures with-in the wards. This preliminary survey was conducted for two days and literature review was also done to collect the existing datasets of various wards required for this research. The prime objective of this survey was to select the study ward and collect the existing dataset of the selected ward. A questionnaire was prepared after this survey and prior to the start of the detailed field survey.

5.2.2.1. Design of Questionnaire

The design of the questionnaire for making a building inventory is the first and foremost step for any seismic vulnerability analysis. A good questionnaire certainly would help in collecting the building information in a systematic way. However, for pre-earthquake seismic evaluation of existing building stocks, there is no standard questionnaire at national and state level. A number of published ITC's research theses were reviewed prior to prepare a Proforma of questionnaire for field survey. This questionnaire was discussed with officials of Central Building Research Institute (CBRI), Roorkee. The ATC 21 data collection form for collecting building information was also considered. The questionnaire already used for a national level project (SHRM) for vulnerability assessment of buildings in Jabalpur was also taken into consideration prior to finalisation of the questionnaire for fieldwork. The details of the questionnaire used in SHRM project are given in the annexure 8. The main objective of preparing this questionnaire was to uncover the flaws in the building structure surveyed and classify these surveyed buildings into the pre defined building class.

The questionnaire was broadly composed of five major sections such as identification data, building configuration and specifications, condition of structure and ambience, vulnerability parameters and building plans, elevations, sections and photographs. The first section (identification data) includes the general building information collected from census database and from field survey. The second section (configuration and specifications) includes the building configuration details, foundation details and structural details. The third section (condition of structure and ambience) includes the general condition of floors, walls and roofs. The fourth section deals in the vulnerability parameters such as seismic load path, soft story etc. The final section of the questionnaire requires building photographs to keep the record of physical condition of the building. The elevation and section drawings are also includes in this form. It also covers the information of damage g\during previous earthquake and repair carried out thereof (Agrawal, 2004).

The data collection form was prepared taking into consideration two main types of construction practice with in the ward namely RCC framed structures and masonry load bearing structures. The RCC and masonry covers 90 % of the existing building structures in the ward. The questionnaire involves a set of parameters, which cover structural configuration and specification, condition of structure and ambience, foundation details and seismic vulnerability parameters. The data collection form was prepared in Microsoft Access and converted into GIS framework at later stage. The detail of these forms is given in the annexure 1.

The municipal ward of Dehradun called "Race Course" was selected for this research work. One of the major factors in taking the present ward for this study was the availability of pre-defined building classes. Most of the other parts of the city have poor quality of construction that cannot be classified in any of the building classes given in HAZUS. The other reason for taking this particular ward as a case study ward was the availability of building information and building foot print map of the ward prepared by Guar (Sur, 2005) in October 2005. Ranjan (Ranjan, 2005) has also calculated the spectral acceleration at 1 Hz, 2 Hz, 5 Hz and 10 Hz for this ward. The spectral acceleration is the PESH parameter required in fragility curve for calculation of damage probability in HAZUS methodology as mentioned in chapter 3.

5.2.2.2. The Study ward - Race course (N)

The Race Course (north) municipal ward has been taken as a study area in Dehradun municipal area for study of vulnerability assessment of building structures. This ward is referred to as ward number-39 in the ward map of Dehradun city. Race course (N) has a total area of 24.248 hectares and a population of 8249 (GOI, 2001a). This ward lies between 30° 18 10² N to 30° 18 56² N latitude and 78° 02 55² E to 78° 02 12² E longitude.

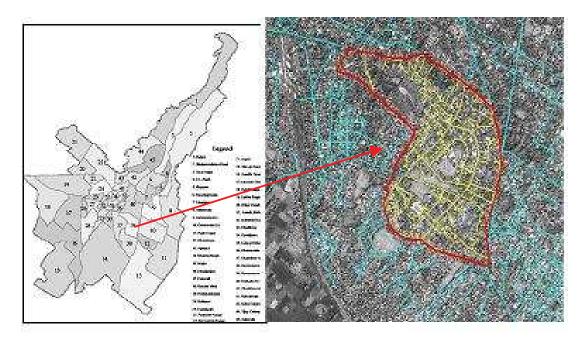


Figure 5-2: Location of study ward in map of Dehradun

The study ward is surrounded by residential colonies namely Chandra Nagar in the west, Racecourse (S) in the south, Dalanwala and Dharampur in the east and Mahadevi K P in the north. The whole north and east corner of the ward was enclosed by 9.0m wide Haridwar road. This road is the one of the major roads within the Dehradun municiple area due to the heavy traffic in peak hours. In the northern part beside Haridwar Road the only Jail of Dehradun is located. The complex is one of the oldest building structures in the city. Most of the existing building structures within this jail complex are old and low-rise buildings. Though most of this ward consists of planned area, unplanned areas also exist, particularly along Haridwar Road. Hence, this ward is characterized by high and middle-

income people along with economically weaker sections. The southern part of the ward has the biggest and highest building structure and has the residential apartments. The structure was constructed by using latest construction technology and all measures were taken to make it earthquake resistance structure. The main ring road and other major roads are wide and properly maintained. Most of the commercial land use is found along Haridwar road in the northern and eastern part. The largest Gurdwara (religious place) and major Medical center (Combined Medical Institute) are the major landmarks in this ward. Also two intermediate colleges and two primary schools have added significance to its land use. In this area use of new construction techniques and good building materials along with old constructions added significant effect in terms of comparative building vulnerability assessment.

5.2.2.3. Subdivision of ward into blocks

The race course ward was sub divided into six blocks namely A, B, C, D, E and F. The division was done on the basis of area divided by major roads with-in the ward. The main reason of sub dividing the ward into blocks was to divide the field schedule on basis of blocks and to identify the buildings on a block basis. The building ID was also given on a block basis. Nearly each block has one landmark building within the ward.

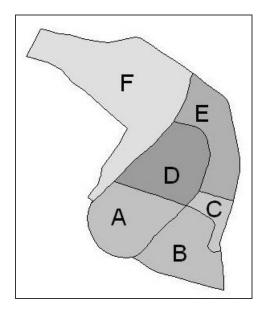


Figure 5-3: subdivision of study ward into blocks

5.2.3. Detailed Survey

During the commencement of the field survey of the selected ward in Dehradun, buildings of each class were identified. The main aim to collect building samples was to identify the building characteristics in the ward and to verify of the Data Entry Form prepared (annexure 1). The details of individual buildings of previous research were not available to the researcher. Due to shortage of time researcher used the available data of previous research and collected missing data from field required for creating a new database for making an updated building inventory of the study ward. Most of the new constructions observed had residential landuse. The prominent building occupancy classes

observed in the ward were residential and commercial. The sampling of buildings was done by taking into consideration the structural elements and configuration of the buildings as the prime factors taken into account for sampling.

The database of 1353 buildings was prepared by researcher using existing and collected information of the buildings in study ward. The random sampling technique was used to collect the building information. The sample of 20-25 representative buildings was taken from each block on the basis of structural properties. The building information was collected on the basis of data collection form prepared for the survey by the researcher. The buildings were surveyed on the basis of numbers taken from the vector layer digitising in ERDAS Imagine and collected information was filled in the data entry form prepared in MS Access. The buildings were selected with the assumption that a selected building represents the construction practice that is prevalent in the selected study ward. The number of this type of building structure was very less in the ward as most of the building structures come under the masonry and RCC building class. The satellite mages of two different years were also compared through visual interpretation prior to the start of the actual field survey.

The priority had been given to the structures having different occupancy such as residential, commercial and education. The new construction was also taken into consideration in selecting building samples. The discrete features visible in the satellite images and features, which were difficult to interpret, was one of the criteria of selecting samples. The discussions were also carried out with local community during the commencement of field survey. This discussion included the general condition of building in last earthquake and earthquake resistance elements used in building construction. The discussion also included the quality of building material used for construction such as cement, steel etc. The discussion regarding supervision of the construction of building was one of the important parts of collecting building information while field survey.

5.3. Data Preparation

5.3.1. Remote sensing data

Satellite Image	Acquiring Date	Ground Resolution	Study Area	Projection System
IKONOS PAN 2005	05 May 2005	1.0 Meter	Dehradun, India	UTM, WGS84
IKONOS MS 2005	05 May 2005	4.0 Meter	Dehradun, India	UTM, WGS84
IKONOS PAN 2001	19 April 2001	1.0 Meter	Dehradun, India	UTM, WGS84
IKONOS MS 2001	19 April 2001	4.0 Meter	Dehradun, India	UTM, WGS84

Table 5:1: Description of remote sensing data used in research

Space Imaging Inc., a US based Earth Observation Company is the premier provider of IKONOS satellite image. IKONOS works on the principle of push broom and simultaneously provides

panchromatic and multispectral images. The panchromatic sensor has 1.0 m ground resolution. It has only single spectral band and the image is in black and white. The multispectral sensor has 4.0 m ground resolution and four individual spectral bands namely blue, red, green and near infrared.

5.3.2. Ancillary Data

The Survey of India (SOI) guide map at 1:20000 scale was used for identification of urban features, visual interpretation and selection of training sets at the time of field verification. Ward boundary map of Dehradun city was collected from MDDA and Nagar Nigam, Dehradun. The ward boundary map was used to identify the ward boundary in the Ikonos image and extract ward area from the imagery.

Map	Scale	Year of Survey	Year of Publication	Study Area
Guide Map	1: 20000	1965-68	1982	Dehradun, India
Ward Boundary Map	1: 20000	2002	-	Dehradun, India

Table 5:2: Description of Ancillary data used in the research

5.3.3. Software Used

1. Arc View 3.2

This software was mainly used for adding the attributes of generated maps in vector layer. The database generated in Microsoft Access in DBF format was joined with attribute table in Arc View.

2. ERDAS imagine

ERDAS Imagine software was used to prepare merged images using broovy transformation followed by application of various contrast enhancement techniques. Finally the product has been taken up for visual interpretation. This final merged thus prepared has the spatial resolution same as the PAN data, but the spectral characteristic is thus improved with respect to the Pan data used for the extraction of urban features. This merge image was later used for the digitization of buildings and roads in ERDAS imagine. The merged image was used extensively during field survey for collecting building information.

3. MS Office

MS word and MS Access were mainly used for report writing and creating the building inventory. All the building data collected from the field has been added in the palmtop in the study ward itself using a Data Entry Form prepared in MS Access. The generated building database in tabular form in MDF format thus saved into the DBF format to transfer it into GIS framework. The care was taken while adding field data in the data entry form that the data of building polygons added in MS Access should have the same ID as the ID given in shape file created in Arc view.

5.3.4. Digitisation of Buildings and Roads

In this step, first the municipal ward boundary map of Dehradun city was digitized on screen based on the municipal ward map (1:20,000) prepared by the Municipal Corporation of Dehradun. Then, the study area was selected and ward boundaries were demarcated. Using ERDAS Imagine software, AOI file were created from the merged IKONOS product for the study ward, Racecourse (N). Finally, using the visual interpretation parameters, the buildings and roads were digitized and unique ID's were assigned on block basis to each building for field data collection.

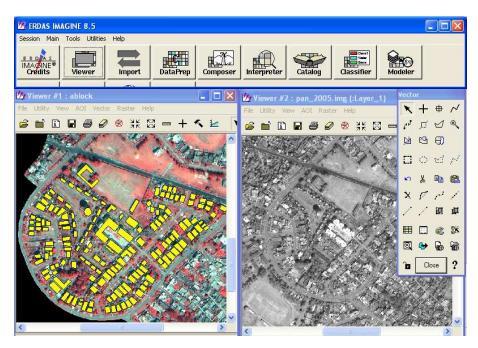


Figure 5-4: Digitisation of ward's buildings on merge Ikonos image

The figure 5.4 shows the digitization of building blocks of ward A on merged image in ERDAS. The digitization was done by using the building information collected from the field through data entry form. The base map thus prepared was verified and corrected during the Pre-Field Session. The digitization process was done on the merged IKONOS image in ERDAS imagine. The building ID's of polygons in the attributes table of vector file was kept checked while digitizing. The missing ID's were noted on separate sheet, which eliminates the error while putting the numbers on building polygons on the print of building map on A0 size paper. Proper care was taken to delete the repeated ID's of building polygons while digitization in ERDAS Imagine. The default values of building ID's of attribute table were used for giving the numbers on building polygons.

Roads were digitized on the basis of reconnaissance surveys done earlier and guide map of ward collected from MDDA. The roads were digitised in ERDAS along the centre lines in a single line to create a shape file in Arc View for roads. Care was taken while digitising the roads in ERDAS that the node snap distance, arc snap distance and weed distances should have the values not more then 0.25 to avoid the problem of overlapping and gaps between the ends of lines. The values were changed every time after commencing the clean and built process of vector file generated.

5.3.5. Building Inventory of study ward

Individual building data or maps were not available for Dehradun city except the ward boundary map; therefore, the data was collected through field surveys of study ward. The large printouts of merged IKONOS image data with building footprints and building ID for each block within the ward was taken for fieldwork along with a data entry form prepared in MS Access to generate the building database. All entries of listed parameters of individual buildings were filled in the data entry form in the ward itself. A laptop was used during the field survey to fill the data of individual buildings in the data entry form prepared in MS Access. In this way, individual building layers were generated editing the existing digital footprint map. The building parameters like (i) Building Shape (ii) Proximity between two adjacent buildings were determined through onscreen visual interpretation using Arc GIS 8.2 and Arc View 3.2. All the building inventory data were stored and assigned to specific buildings and thus a complete database for earthquake vulnerability was prepared. Figure 5.5 gives the example of data collection form used by researcher for field survey.

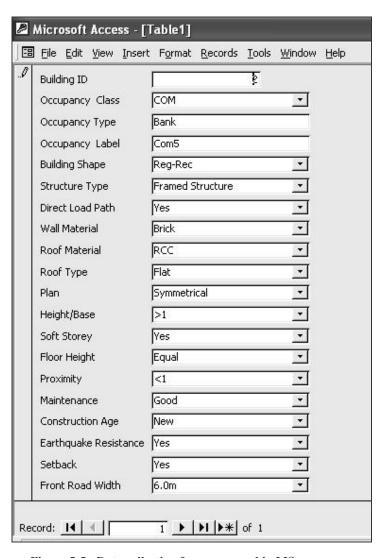


Figure 5-5: Data collection form prepared in MS access

5.3.6. Building occupancy in study ward

The predominant occupancy in Racecourse ward is residential. Figure 5.4 shows the building foot print map of study ward. The earlier academic research (Sur, 2005) on this ward as well as data collected from the field by the researcher was used to prepare building foot print map of the ward. The map gives the description of various occupancy in study ward. More than 80% of buildings account for residential use. Among all residential types mentioned in table 5.1 the number of independent houses or single-family houses has maximum number of units in the ward. The residential commercial and commercial use accounts for about 11% and 4% respectively. The residential-commercial and commercial occupancy has maximum units along Hardwar road in blocks B, C and E. These blocks have high building density of private shops in single-family houses. The other building uses contribute negligible proportion except Jail (2.5%) and transport (2%).

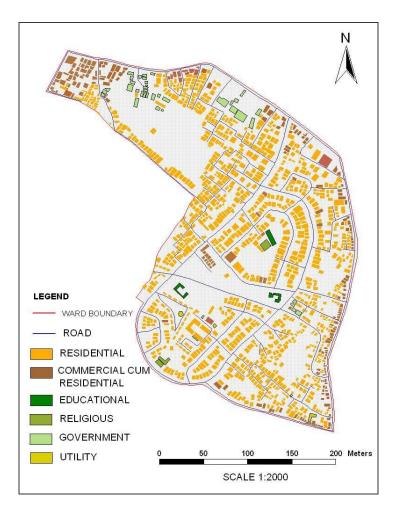


Figure 5-6: Description of occupancies in study ward in building foot print map

	Total	RES	COM	RES+COM	REL	GOV	EDU	UTL
Distribution	1353	1093	52	157	3	37	3	6
Percentage	100	80.8	3.8	11.6	0.2	2.7	0.2	0.4

Table 5:3: Distribution of various occupancies in study ward

5.3.7. Building structures in study ward

In Race Course (N) ward, the unreinforced masonry structures have the prime share of 65%. Among all 1353 building structures in the ward, the number of unreinforced masonry type has 888 building structures. Where as the number of RC framed type has 465 building structures. Most of the RC framed structures are limited to A and D block. Majority of building structures in B, C, E and F block comes under unreinforced masonry structures. The RC framed buildings represents the new construction and most the structures have good maintenance. The unreinforced structure represents the old construction and have poor maintenance.

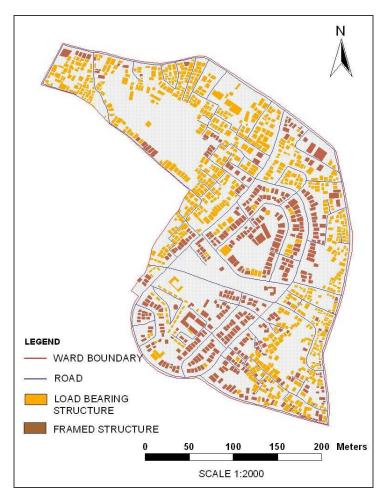


Figure 5-7: Distribution of building structure types in study ward

	Total	Framed Structure	Load Bearing Structure
Distribution	1353	463	890
Percentage	100	34.2	65.78

Table 5:4: Distribution of building structure types in study area

5.3.8. Building Heights in study ward

All the building structures in ward are divided into two categories based on their heights. The low rise buildings and mid rise buildings. The height of low-rise buildings is ranges from 15 feet to 20 feet. The number of storeys of low-rise buildings ranges from G and G+1. The height of mid-rise buildings is ranges from 35 feet to 50 feet. The number of storeys of mid-rise buildings ranges from G+2 to G+4. In Race course ward, more than 80% of construction falls under low-rise category. The number of low-rise structures in the ward is 1136 and number of mid-rise structures in the ward is 217.

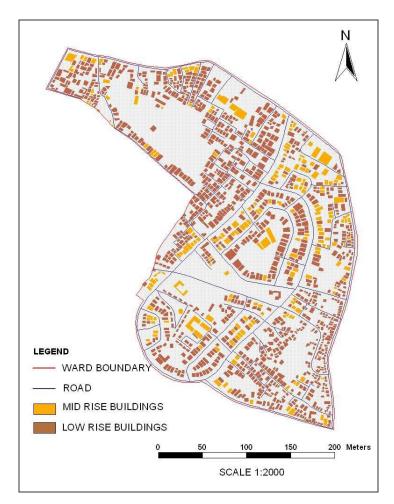


Figure 5-8: Distribution of buildings in study ward based on height ranges

	Total	Mid Rise G+2 - G+4	Low Rise G, G+1	
Distribution	1353	217	1136	
Percentage	100	16.0	83.9	

Table 5:5: Distribution of buildings based on height ranges in study ward

5.4. Summary

This chapter described the method of data collection through institutional survey and field survey of study ward. The field work stages and pre field preparation was also discussed in this chapter. The discussion on preparation of questionnaire in the form of Data Collection Form (DCF) is also included. It also included the process of preparing the building foot print map of the study ward. The outcome and results of this data collection will be discussed in the next chapter.

6. Results and Discussions

This chapter presents the results of the loss estimation of the building structures in the study ward in Dehradun city using the HAZUS methodology. The damage algorithm of probability calculation by the HAZUS methodology and stepwise calculation of damage probability of one the four building classes at given ground motion is explained in detail in this chapter. It also covers the discussion on the preparation of building inventory, data collection from field survey, seismic and soil data collected from various literatures and used for this study. It also covers a discussion on use of model building types of HAZUS for risk assessment of buildings in study ward for risk assessment.

6.1. Discussion on Seismic and soil data

The earthquake scenario selected was a hypothetical scenario, which is comparable in magnitude to the 1999-Chamoli earthquake in Uttaranchal. It estimates the damage if similar earthquake like Chamoli would occur close to Dehradun. The characteristic parameters of Chamoli earthquake are given in the table 6.2 (EERI, 1999). The effect of this earthquake was also experienced in Dehardun city. Many buildings in Dehradun (125 km west of Chamoli) sustained damage (EERI, 1999). For example, in some old buildings of the Survey of India, the gable masonry collapsed and there was severe cracking along the junctions between the pitched roof and the masonry walls.

Event Name	Country	State	District	Station Name	Date of Event	Local Time	Major Thrust
Chamoli 1999	India	Uttaranchal	Chamoli	Teri	29-Mar-99	12.35 am	MBT - MCT

Characteristic Parameters						
Origin N (degree)	30-17-82 N					
Origin E (degree)	79-33-84 E					
Local (Richter) Magnitude (M _L)	6.8					
Surface Wave Magnitude (M _s)	6.6					
Body wave Magnitude (m _b)	6.3					
Moment Magnitude (M _w)	6.8					
Fault Type	Strike Slip					
Fault Depth (Km)	15					
Fault Length (Km)	30					
Dip Angle (degree)	9					
Circular source radius (Km)	1.98 to 2.96					
Epicentre Distance from Station (Km)	80					
Hypocentral Distance from Station (Km)	89.3					

Table 6:1: Characteristic parameters of Chamoli earthquake

Source: (EERI, 1999)

The other reason of taking this particular event is the availability of strong motion record required for this study. Ranjan (Ranjan, 2005) calculated the spectral acceleration using ground motion data of

Chamoli earthqauke at 1 Hz, 3 Hz, 5 Hz and 10 Hz frequencies at 5% damping. The strong motion data used by Ranjan (2005) were recorded at Teri (a place which is 50 km away from Dehradun). The present study ward comes under the Dharampur site (No. 26) (Ranjan 2005).

The equation 6.1 is used to convert the spectral acceleration to spectral displacement for a given seismic period.

Where

 S_A = Spectral Acceleration (g)

 S_D = Spectral Displacement (inches)

T = Time Period (sec)

Table 6.2 shows the values of spectral displacement (S_D) calculated from equation 6.1 with corresponding spectral acceleration and time period.

Freq - f	Time Period-	Spectral	Spectral
(Hz)	T (sec)	Acceleration - S _A	Displacement - S _D
		(g)	(inches)
1	1	0.08	0.784
3	0.333	0.43	0.467
5	0.20	0.31	0.121
10	0.10	0.20	0.0196

Table 6:2 - Spectral Displacement corresponding to spectral acceleration

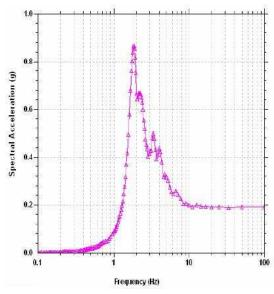


Figure 6-1: Response spectra of study ward

Source: (Ranjan, 2005)

Figure 6.1 shows the response spectra calculated by Ranjan using SHAKE computer program at various ground frequencies.

6.2. Discussion on building inventory

In the HAZUS methodology, apart from the primary parameters, which have already been mentioned in chapter 2, the building inventory classification consists of a two-dimensional matrix (NIBS, 2002). It is based on building structure type (annexure 9) and occupancy type (annexure 4). In this section the occupancy type is taken into consideration, while the building structure typology will be discussed under the building classification heading later in this chapter.

The occupancy type inventory of the general building stock in the HAZUS methodology was prepared on the basis of its building occupancy. The main aim of making a building inventory is to group buildings with similar characteristic and classify them it in a group of pre-defined building class. The data collection was done to know the existing building characteristic with in the ward and verify the HAZUS building classification used in this study for the assessment of building vulnerability. This helped to analyse the adoption of selected model building types in the ward.

The numbers and percentage of other occupancy classes existing in the ward is summarised in the table 6.3. The detailed description of various occupancy classes is given in the annexure 4.

			General Occupancy Type							
		RES	СОМ	RES+COM	REL	GOV	EDU	UTL	Total	%
	Res1	949	-	-	-	-	-	-	949	70.14
S	Res3	133	-	-	-	-	-	-	133	9.83
Р	Res4	6	-	36	-	-	-	-	42	3.10
E	Res5	4	-	-	-	-	-	-	4	0.30
С	Res6	3	-	-	-	-	-	-	3	0.22
1	Com1	-	44	115	-	-	-	-	159	11.75
F	Com2	-	1	-	-	-	-	-	1	0.07
I	Com3	-	6	1	-	-	-	-	7	0.52
С	Com4	-	-	1	-	-	-	-	1	0.07
	Com5	-	-	3	-	-	-	-	3	0.22
0	Com6	-	1	-	-	-	-	-	1	0.07
C	Com8	-	-	1	-	-	-	-	1	0.07
U	Rel1	-	-	-	3	-	-	-	3	0.22
P	Gov1	-	-	-	-	20	-	-	20	1.48
A	Gov2	-	-	-	-	17	-	6	23	1.70
N	Edu1	-	-	-	-	-	1	-	1	0.07
С	Edu2	-	-	-	-	-	2	-	2	0.15
Υ	Total	1095	52	157	3	37	3	6	1353	
	%	80.93	3.84	11.60	0.22	2.73	0.22	0.44		

Table 6:3 – Distribution of buildings in study ward General occupancy (column) and specific occupancy (row)

Table 6.3 represents the number of buildings in the study ward based on occupancy type. The column in the table represents the number of buildings in general occupancy class. The row in the table represents the number of buildings in each specific occupancy class as defined in HAZUS. The most frequent occupancy type is residential and more than 80 percent of the buildings are single-family

dwellings, multiple family dwellings, temporary lodging, institutional dormitories and nursing homes, according to the HAZUS classification (NIBS, 2002). The RES1 occupancy is found to be having maximum numbers of building structures. The second most prevalent occupancy in the ward is residential combined with commercial, which has a total percentage of 11.75 in the study ward. This mixed class was not found in the HAZUS building occupancy classification. The class was added in the occupancy class in this research work later after reconnaissance survey. Few building structures were found to be having other mixed occupancy within the principal occupancy class. For example a commercial coaching centre was found in the residential building having 10 to 12 classrooms. The building can be assigned to three different occupancy classes namely residential, commercial and educational. In this case the principal occupancy type was selected and building was assigned to residential class.

The building character varies substantially between various blocks in the ward. In figure 6-2, Blocks A and D were found to be well planned and most of the building structures had framed structures. The proximity was well maintained and adequate earthquake measures were taken while construction such as horizontal banding, minimum soft storeys and setbacks.

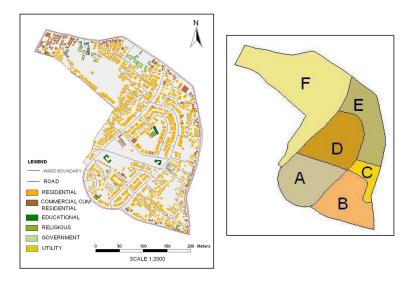


Figure 6-2: Building foot print map and building block map

Blocks B, C, E and F were found to be irregularly planned and most of the structures had load-bearing construction. The building density was very high in a few areas of these blocks as compare to A and D block. In few cases it was very difficult to distinguish between the plot lines of two adjoining houses due to irregularity in plot boundary and smaller plot area of 20 to 25 sq metres. Most of the building structures in B, C, E and F blocks were not well maintained and lack any sort of earthquake resistant construction. Most of the new buildings were found to be using good construction technology and adopted earthquake resistance measures. Picture 6.1 shows the example of under construction building in the ward. The picture gives the ides of using earthquake resistance elements in the building. The framed construction in left picture and lintel and plinth beams in right picture provides the good example of construction technique in the buildings.





Picture 6-1: Example of under construction building in study ward

Source: Field Survey

6.3. Building classification

As mentioned earlier the building inventory classification consists of two-dimensional; matrix relating building structure types and occupancy classes. The occupancy type inventory has already been discussed in above section. The building structure types are grouped in terms of basic structural systems according to the model building types from FEMA-178 (FEMA 1992). A detailed description of model building types is given in annexure 9.

The HAZUS methodology divided the model buildings types into 36 categories based on their structural composition and height ranges. The detailed description of model buildings and their structural properties is given in the HAZUS manual (5.2.1 HAZUS 99). The HAZUS building classification considered five types of building frames with wall composition commonly used in USA. The building frames are based on local building material available in the country and local construction practices of the region. The five types of building frames used in the HAZUS methodology are wood frame, steel frame, concrete frame, RCC frame and masonry frames. To use and adopt this classification for present study ward it was necessary to discuss these classes with structural experts. Apart from their structural properties and their adoption in study ward, the discussion also included the modification in these classes to match them with construction practices in the study ward.

The two most prevalent building structural system exists in the study ward are RCC framed structure and load bearing structure. The RCC framed structure building has a composition of RCC column and RCC beam as a structural element. Reinforced masonry is a construction system where steel reinforcement in the form of reinforcing bars or mesh is embedded in the mortar or placed in the holes and filled with concrete or grout. By reinforcing the masonry with steel reinforcement, the resistance to seismic loads and energy dissipation capacity can be improved significantly. Picture 6.2 provides the example of structural elements used in RM model building type in study ward.



Picture 6-2: Example of framed structure (RM) in study ward

Source: Field Survey

The masonry infill walls are constructed with burnt bricks and laid with cement mortar. The roofs and floors are composed of RCC and generally cast at the site. These roofs and floors are supported on interior beams and columns of RCC. These roof and floor acts as a diaphragm and transfer the lateral load to vertical structural elements. In few cases while doing field survey, RCC framed with Reinforced Brick Concrete (RBC) roof structures were noticed. This RCC framed and RBC roof composition was limited to low rise buildings (upto first storey) and old age constructions. The strong reason of using this composition was to lower the construction cost by not using cement in the roof construction. The cost of cement is quite high as compared to burnt bricks in the Indian context.

Load bearing structures generally do not have reinforcement in the structural elements as well as infilled masonry wall. The load bearing structural composition uses a brick column as a structural element. These brick columns transfer the lateral load of horizontal elements to the ground and support roof and floor. The structural elements as well as infill masonry walls are constructed with burnt bricks laid with cement or lime mortar. The roof and floors are composed of RBC and generally uses a burnt brick to cast these horizontal elements. The earlier research (Guar 2005) categorizes load bearing construction type into reinforced and unreinforced masonry infill wall for this study ward. The combination of load bearing structure with reinforced wall was limited to old construction. Few structures were observed in the study area with this type of structural properties. The reinforced wall are constructed of burnt bricks and steel bars of 6mm to 10mm diameter are laid in the wall as well as in the brick columns to overcome the lateral load on the structural elements. This reduces the size of columns and perimeter walls. The reinforcement is laid at every third or fourth course of the brick wall.

After discussing these model-building classes in details with experts from various organizations and academic institutes, only two model building types were selected for this study namely Reinforced Masonry Bearing Wall with Precast Concrete Diaphragms (RM2) and Unreinforced Masonry Bearing Walls (URM) (NIBS, 2002).

Model	Label	Model Name	Height			
No			Range	Stories	Stories	Height
31	RM2L	Reinforced Masonry Bearing Wall	Low Rise	1-3	2	20 ft
32	RM2M	with Precast Concrete Diaphragms	Mid Rise	4-7	5	50 ft
34	URML	Unreinforced Masonry Bearing Walls	Low Rise	1-2	1	15 ft
35	URMM	omeniored Masonly Bearing Walls	Mid Rise	3+	3	35 ft

Table 6:4: Description of model building types selected for ERA in study ward Source: HAZUS Manual





Picture 6-3: Example of RM2M building in study ward Source : Field Survey

The general description of RM and URM model buildings is given in table 6.4. The detailed descriptions of these model-building types are given in the annexure 6. However the structural properties of these model-building types do not resembles exactly with the structural properties of existing building structures in the ward.

The structural properties of RM2 model class in the HAZUS methodology resembles the structural properties of framed structure with masonry infill walls in the study area. The only difference between the structural properties of two classes is the way of casting the diaphragms. In case of RM2 class the roof and floor diaphragms are typically composed of pre-cast concrete elements where as in case of framed structure roof and floor diaphragms are constructed on site. The way of casting the diaphragms as well as structural elements can subsequently affect the overall strength of the structure. In pre-cast construction the proportion of cement, concrete and steel bars in the structural elements is well specified. The pre-cast building structural elements are factory-made and under strict quality control. The quality control in pre-cast concrete is one of the major factors that increases the strength of structural elements and makes them earthquake resistance. Where as in case of cast in-site construction in the study ward for residential buildings, quality control of building material mainly depends upon the individual capacity to invest on the proposed structure. The variation in proportion of steel and cement in casting the same structural elements for same building affect the stability of structure.





Picture 6-4: Example of URML building in study ward Source : Field Survey

The structural properties of URM class are more or less similar to the structural properties of load bearing structure type. Picture 6.4 gives the example of URM model building type in ward. The perimeter walls in some cases were constructed of reinforced masonry. The combination of load bearing structure with reinforced masonry was not matching with this class. The assumption was made and this class was merged with URM class. The building inventory was prepared thereafter considering these two model-building types. The already prepared inventory was than divided into the four mentioned classes based on their structural properties and height ranges.

The distribution of buildings based on these model classes is given in the table 6.5. The column of table represents the number of buildings in each model building types. The row of table represents the number of model type buildings in each specific occupancy.

Table 6.5 indicates that 65 percent of the building structures are in the URM category and 35 percent in the RM2 category. The high percentage of unreinforced masonry structures (URM) in the ward represents the poor and moderate construction quality of building structures. The building structures constructed without reinforcement are generally more vulnerable to earthquake risk. More than half of the building structures with a low height range are in this class. On the basis of occupancy 481 structures have the URM class and comes in the RES1 category. The reinforced masonry structures with low height range (RM2L) have the second highest numbers of building structures in the ward. This model class has the 261 numbers of residential units in the ward.

		Model Building Type						
		RM2M	RM2L	URMM	URML	Total	%	
S	Res1	84	261	119	481	945	69.84	
Р	Res3	9	29	4	93	135	9.98	
E	Res4	9	3	2	28	42	3.10	
С	Res5	0	0	4	0	4	0.30	
F	Res6	1	1	1	0	3	0.22	
Ī	Com1	9	39	41	70	159	11.75	
C	Com2	1	0	0	0	1	0.07	
	Com3	0	1	6	1	8	0.59	
0	Com4	0	1	0	0	1	0.07	
С	Com5	1	2	1	0	4	0.30	
С	Com6	1	0	0	0	1	0.07	
U	Com8	0	0	0	1	1	0.07	
P A	Rel1	0	3	0	0	3	0.22	
N	Gov1	2	2	1	15	20	1.48	
C	Gov2	1	3	6	13	23	1.70	
Υ	Edu1	1	0	0	0	1	0.07	
	Edu2	1	0	1	0	2	0.15	
	Total	120	345	186	702	1353		
	%	8.87	25.50	13.75	51.88			

Table 6:5- Distribution of four model building types in study ward

6.4. Assessment of building risk

The HAZUS methodology calculates the building damage in terms of probability of damage of particular model building types for pre-defined damage states. The probability of damage is calculated in relationship with given ground motion parameters to evaluate the building performance for a particular seismic event. The HAZUS methodology follows the seven basic steps for the calculation of damage probability of a particular model building type. The HAZUS methodology flow chart has discussed in chapter 3 (refer figure 3.3).

The damage algorithm has been discussed earlier in section 3.4 of chapter 3. Steps for calculating damage probability for RM2M model class for low design code are shown below.

Step 1. Input requirement as per HAZUS methodology

Model building type including height – RM2M Seismic Design Level – Low Design Level

Step 2. Generation of Response Curve for study ward at 0.3 second and 1.0 second

A) Parameters for Response Curve:

Spectral acceleration, S_A [0.3 second] = 0.43 g (earthquake magnitude = 6.8)

Spectral acceleration, $S_A[1.0 \text{ second}] = 0.08 \text{ g}$ (earthquake magnitude = 6.8)

Spectral Displacement, S_D (inches)

B) Calculate Spectral Displacement corresponding to Spectral acceleration using relation given in equation 6.1.

Freq - f	Time Period-	Spectral Acceleration -	Spectral Displacement
(Hz)	T (sec)	$S_{A}(g)$	- S _D (inches)
1	1	0.08	0.784
3	0.333	0.43	0.467
5	0.20	0.31	0.121
10	0.10	0.20	0.0196

Table 6:6- Spectral Displacement and Spectral acceleration in study ward

C) Generate response spectra

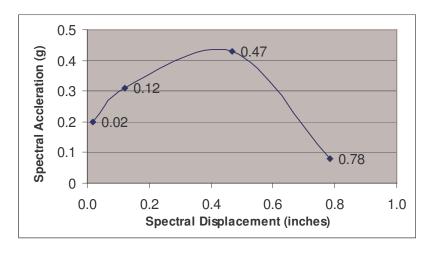


Figure 6-3: Example of response spectra in study ward

Step 3. Generation of Capacity Curve of RM2M model building type

- A) Parameters for Capacity Curve:
 - a) Yield Capacity Point (Dy, Ay)
 - b) Ultimate Capacity Point (Du, Au)

B) Values of parameters taken from HAZUS

Capacity Curve Parameters for Low Code Seismic Design Level						
	Yield Capaci	ty Points	Ultimate Capacity Points			
Туре	Dy (in.)	Ay (g)	Du (in.)	Au (g)		
RM2M	0.35	0.11	2.31	0.22		

Table 6:7 - Capacity Curve Parameters of RM2M class (appendix 15)

C) Generate Capacity Curve

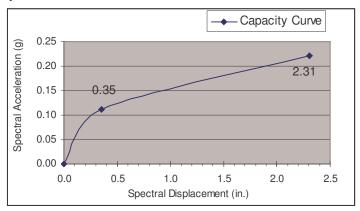


Figure 6-4 - Capacity curve of RM2M class

Step 4. Calculate peak building response (Peak spectral displacement, S $_{\rm d}$)

A) Overlay response curve and capacity curve

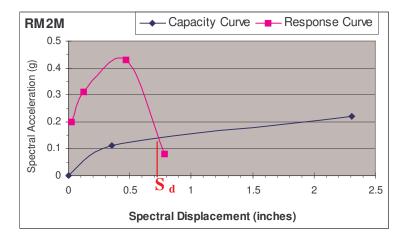


Figure 6-5: Peak building response of RM2M class

B) Calculate peak building response

Peak Building Response (inches) , S $_{\rm d}$					
Model Building	RM2M				
SD (inches)	0.725				

Step 5. Calculate Cumulative Probability for RM2M class

A) Parameters for Fragility curve for RM2M class

Structural Fragility Curve Parameters of RM2M Model Class								
Low Design Code								
	Slight Mode		erate	ate Extensive		Complete		
Type	Ŝ _{d.S/S}	βs	Ŝ _{d.S/M}	βм	Ŝ _{d.S/E}	βЕ	Ŝ _{d.S/C}	βс
RM2M	1.2000	0.8400	1.9200	0.8100	4.8100	0.7700	13.1200	0.9600

Table 6:8- Fragility curve parameters of RM2M class (appendix 10)

B) Calculate Cumulative Probability for RM2M class using relation given in equation 6.2

Spectral Displacement, $S_d = 0.725$ inches (Peak Building Response)

$$P[ds \mid S_d] = \Phi \left[\frac{1}{\beta_{ds}} \ln \left(\frac{S_d}{\overline{S}_{d,ds}} \right) \right]$$

where:

 $P [ds | S_d] = probability of being in or exceeding a damage state, ds.$

S_d = given spectral displacement (inches)

 \hat{S}_{ds} = median value of S_{d} at which the building reaches the threshold of damage state, ds.

 β ds = Lognormal standard deviation of spectral displacement of damage state, ds

 Φ = Standard normal cumulative distribution function

				Х		Υ	
Damage State	S _d	Ŝ dS	β_{ds}	$S_d / \hat{S}_{d.ds}$	LN(X)	[L N (X)] / β d	Ф[Y]
Slight	0.725	1.2000	0.8400	0.604	-0.504	-0.600	0.274
Moderate	0.725	1.9200	0.8100	0.378	-0.974	-1.202	0.115
Extensive	0.725	4.8100	0.7700	0.151	-1.892	-2.458	0.007
Complete	0.725	13.1200	0.9600	0.055	-2.896	-3.016	0.001

Table 6:9- Showing calculation of cumulative probabilities of RM2M class

In the table 6.9, X and Y represents as:

$$X = S_d / \hat{S}_d$$
 and $Y = [L N (S_d / \hat{S}_d)] / \beta_d$.

The values of Cumulative probabilities were summarized as

Probability	0.274	0.115	0.007	0.001
Cumulative	P[S Sd]	P[M Sd]	P[E S _d]	P[C Sd]

Table 6:10 – Cumulative probabilities of Rm2M class

where

 $P[S | S_d]$ = probability of being in or exceeding a slight damage state, S.

 $P[M \mid S_d] = \text{probability of being in or exceeding a moderate damage state, M.}$

P [E | S_d] = probability of being in or exceeding an extensive damage state, E.

P [C | S_d] = probability of being in or exceeding a complete damage state, C.

Step 6: Calculate the discrete damage probabilities

Probability of complete damage, P [C] = P [C | S_D] = 0.0013 Probability of extensive damage, P [E] = P [E | S_D] - P [C | S_D] = 0.0057 Probability of moderate damage, P [M] = P [M | S_D] - P [E | S_D] = 0.1076 Probability of slight damage, P [S] = P [S | S_D] - P [M | S_D] = 0.1597 Probability of no damage, P [None] = 1 - P [S | S_D] = 0.726

Step 7. Generate Damage probability matrix for RM2M class

Damage Probability Matrix									
Model type	Slight	Moderate	Extensive	Complete					
RM2M	0.1597	0.1076	0.0057	0.0013					

Table 6:11 - Damage probability matrix of RM2M class

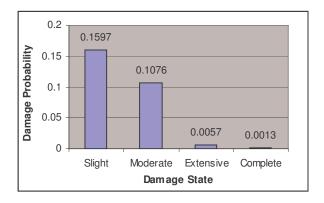


Figure 6-6: Damage Probability graph of RM2M class

Figure 6.6 shows the damage probabilities calculated by HAZUS method of RM2M model-building type in the study ward. The graph represents the damage probability of buildings having similar structural properties with RM2M HAZUS model building type. The graph shows the buildings having RM2M structure properties are most vulnerable to slight damage and least vulnerable to complete damage

6.4.1. Damage probability of all four model building types

The damage probabilities of all four model-building types were calculated by method explained above. Table 6.12 provides the values of peak building response of all four model-building types. The values of spectral displacement for all four model-building types were calculated from peak building response spectra given in the appendix 14a, 14b, 14c, and 14d.

	Peak Building Response (inches)						
Model Building	RM2L RM2M URML URMM						
SD (inches)	0.70	0.725	0.64	0.725			

Table 6:12 – Peak building response values calculated from (appendix 13)

Table 6.13 provides the values of cumulative probabilities of all four model-building types. The relation given in equation 6.2 is used to calculate the damage probabilities for each damage state. The fragility curve parameters were taken from the HAZUS manual (NIBS, 1999). The fragility curve parameters for four-model building types are given in appendix 11.

Model	Cumulative Probabilities						
Туре	Slight	Moderate	Extensive	Complete			
RM2L	0.4893	0.3213	0.0967	0.0039			
RM2M	0.2743	0.1146	0.0070	0.0013			
URML	0.6736	0.4112	0.1470	0.0320			
URMM	0.5613	0.2740	0.0457	0.0055			

Table 6:13- Cumulative probabilities of all four-model building types

The damage probability matrix was thus derived for all model-building types for all damage states by using damage algorithm described in section 3.2 of chapter 3. Table 6.14 provides the discrete damage probabilities derived from cumulative probabilities given in table 6.13. The damage probability matrices below represent the performance of four model building type for a low seismic design code.

Model	Discrete Probabilities (DPM)						
Туре	Slight	Moderate	Extensive	Complete			
RM2L	0.168	0.2246	0.0928	0.0039			
RM2M	0.1597	0.1076	0.0057	0.0013			
URML	0.2624	0.2642	0.115	0.032			
URMM	0.2873	0.2283	0.0402	0.0055			

Table 6:14 - Damage Probability Matrix (DPM) of four model building types

The figure 6.7 shows the comparative analysis of damage probabilities calculated by HAZUS method of four model-building types in the study ward. It shows the URM structures are at higher risk for complete damage as compare to RM2 structures of the study ward

The graph indicates the building having structural properties similar to URML model building type is the most vulnerable among all four-model building types. The buildings having structural properties similar to RM2M class is least vulnerable to earthquake damage. Among the same structure type in URM class, the URML is more vulnerable than URMM class. The URML class will suffer maximum complete and extensive damage when an earthquake having characteristic parameters similar to Chamoli earthquake (M6.8) occurs close to Dehradun

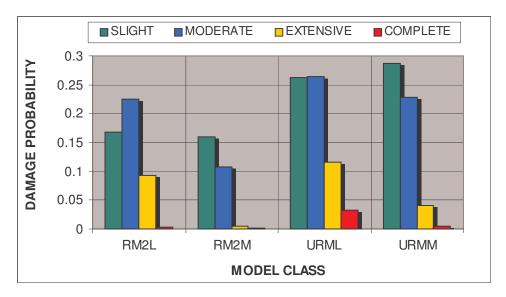


Figure 6-7: Damage Probability graph of four model-building types

The result seems to be not very accurate for URMM and URML class. The URMM class has more number of storys than URML class. The damage to URMM class should be more than URML class. In general the principal of direct relation of height to damage does not satisfy here. Similarly in case of RM2 structures also the high-rise buildings are less vulnerable to earthquake damage. Which is again in contrast to the general principal of relation between the height and vulnerability. In general the graph indicates the construction of high-rise buildings in a study ward are safer then construction of low rise buildings.

6.5. Discussion

The results concluded the damage probability calculated by HAZUS method does not gives very realistic results for earthquake risk evaluation in study ward. The method gives good results at the broad level evaluation. The results seem not to be very accurate for fine level risk evaluation. The parameters like building response and damage curves of US based building classes could be one of the major factors of getting these results. The accurate values of building capacity and damage function should be needed to get the more realistic results of risk evaluation of buildings in study ward. The difference in structural properties of RM2 and URM classes with structural properties of framed and masonry buildings in study area could be one other reason of getting inaccurate results of building damage. The results of earthquake risk evaluation by considering ground conditions of study ward in Dehradun and structural properties of buildings in US based on HAZUS building classification are shown in the form of four risk map mentioned below. The maps in figure 6.8, 6.9, 6.10, and 6.12 describe the probability of each damage state all four-model buildings in the ward.

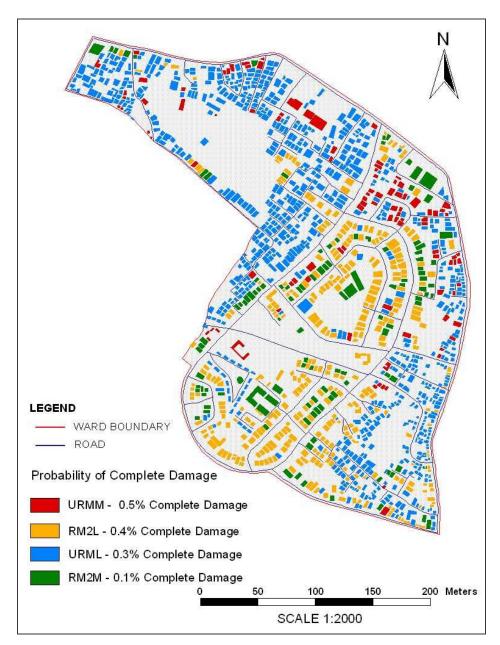


Figure 6-8: Probability of complete damage of model buildings in study ward

Figure 6.8 represents the complete damage probability of four model-building types in study ward.

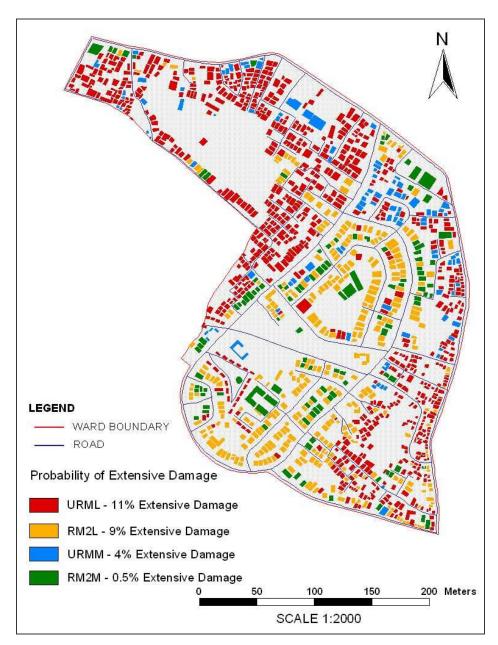


Figure 6-9: Probability of extensive damage of model buildings in study ward

Figure 6.9 represents the distribution of building having extensive damage to four model-building types in study ward.

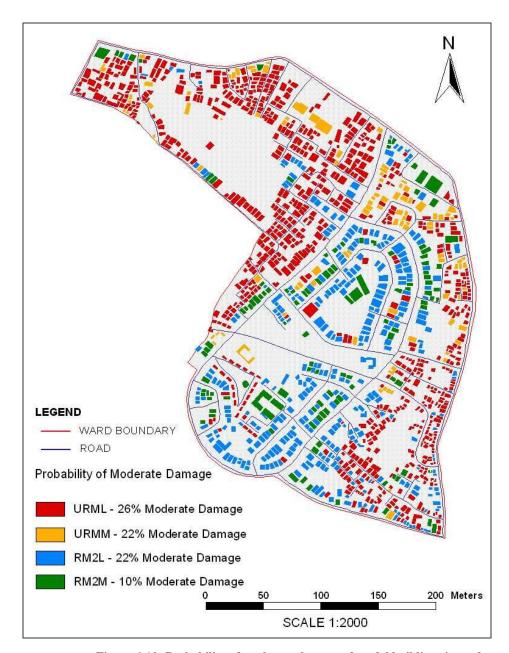


Figure 6-10: Probability of moderate damage of model buildings in study ward

Figure 6.10 represents the distribution of building having moderate damage to four model-building types in study ward.

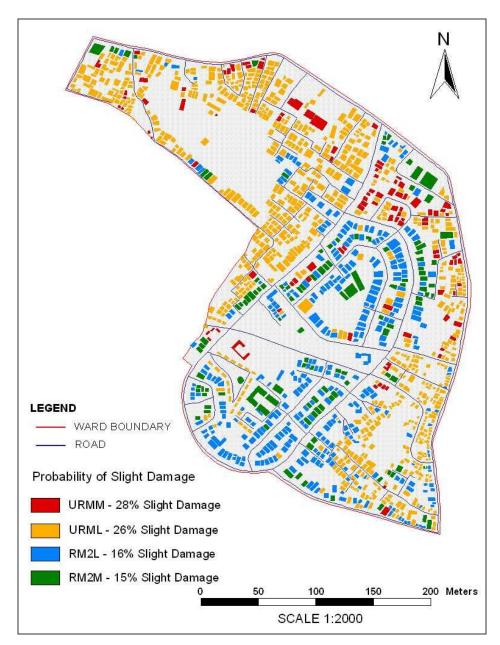


Figure 6-11: Probability of slight damage of model buildings in study ward

Figure 6.11 represents the distribution of building having slight damage to four model-building types in study ward.

7. Conclusions and recommendations

The chapter presents the conclusions made in the form of answers to the research questions and recommendations for future research. The main objective of the research was to analyze the applicability of HAZUS model for the assessment of earthquake risk on buildings in India. The municipal ward of Dehradun was taken as the case study ward to test the HAZUS model in Indian condition.

The frequent occurrence of damaging earthquakes clearly demonstrates the high vulnerability of urban India. There is an urgent need to assess the seismic vulnerability of buildings in urban areas of India as an essential component of a comprehensive earthquake disaster risk management policy. The country certainly required a technical skills and trained manpower to implement any earthquake risk assessment programme. The present study is one of the few attempts to try to look more into earthquake risk assessment in India.

7.1. Conclusions

The whole research was broadly divided into four major sections. The first section gave a review of risk assessment methods in India and in other countries. The second section dealt with the identification and generation of the dataset (seismic, ground motion, building response and damage functions) required for using HAZUS methodology in a study area. The third section dealt with the possible modifications required to use HAZUS based building classifications in a study area in India. This also included the discussion with field experts of various institutes and organizations on the issue of using the HAZUS based building classes in the Indian context. The fourth section dealt with tested the HAZUS methodology for risk assessment of buildings in a study ward. This section also included the modifications needed in terms of parameters for the adoption of this methodology in study area.

In the following section the research questions will be reviewed, and will be answered where possible.

Objective 1.

To give an overview of the various earthquake risk assessment (ERA) methodologies used in India and in other countries.

Q 1.1 What is the status of development of earthquake risk modeling in India?

The study of risk assessment methods in India concludes that the lack of awareness of benefits of risk evaluation limits this process to very few Indian cities. The main cities where the study has been carried out for earthquake reduction are Bhuj (Gujarat), Chamoli (Uttaranchal), Jabalpur (Madhya Pradesh), and Delhi. The study of ERA has been carried out in Bhuj, Gujarat by commercial firm Risk Management Solutions of India (RMSI). The detail of this study was not available to the researcher. The seismic microzonation studies carried out by CBRI in Delhi, Jabalpur and Dehradun. The joint study by NSET and DEQ-UoR was carried out in 2000 for damage assessment in Chamoli of Chamoli earthquake (M6.8, 1999) (NSET, 2000).

The case study (Jabalpur state, MP) held at National level on seismic evaluation. This study was based on a limited sample size of representative buildings. The methods adopted in the study were too

general and risk classification is presented in simplified terms of low, moderate and high risks due to the limitations of the available database. The DEQ-UOR in collaboration with Norway is working on developing the HAZUS based methodology for Dehradun city considering all technical aspect of seismic and ground motion and structural aspect of building structures. The detail was not available to the researcher as the process is still in progress and unpublished report is generally not shared to the students from other institutes.

Q 1.2 What are the differences in techniques and methods used in India and other countries for ERA?

In India, the seismic evaluation was done by using two techniques such as quantitative assessment with demand capacity ratio (DCR) approach and qualitatively with rapid screening process (RSP) approach. In most of the case studies in India, the RSP method has been used extensively for ERA of buildings. It is a qualitative method based on the performance of building elements related to building configuration (height, structure, shape, soil condition etc.) in seismic events. This method does not consider the structural detail of buildings. In the absence of complete building information it gives a very approximate results, which are only suitable for preliminary seismic evaluation. DCR covers demand-capacity computation, which evaluates the measure of capacity of the building to resist in the seismic shocks. The DCR method uses the linear analysis method of risk evaluation. The DCR method requires lots of engineering inputs and assesses the vulnerability of building by considering every structural member of the structure. Where as methods devolved in other countries such as HAZUS considered the structural properties of buildings to evaluate the risk. The HAZUS method uses non-linear analysis method for doing ERA, which is based upon the structural equations and calculations. This method can predict the non-linear behaviour of the structural system much more realistically for load and displacement levels

Objective 2.

To identify the parameters (for ground motion, seismic data, building information and damage curves) required in the HAZUS model for ERA for building structures in Dehradun city.

Q 2.1 Which parameters are available and what can be generated to run HAZUS model in Dehradun city for ERA for building structures?

The HAZUS methodology requires various parameters, which can be categorized into four main parts, namely earthquake characteristic parameters, ground motion parameters, building inventory classification and damage functions.

- a) The earthquake characteristic parameters include earthquake location, fault characteristics, and source information. The list of seismic parameters required to run HAZUS is given in table 6.1. Most of these parameters are available for ERA in Dehradun using scenario earthquake.
- b) The ground motion parameters include the soil classification, soil amplification factors, spectral acceleration and spectral displacement. The researcher could not find ground motion data required for study area published by government and non-government organization in India. The researcher referred an academic research data for the present research.
- c) The Building Inventory Classification (BIC) requires building occupancy classification and building structural classification. The building occupancy classification was generated by field

survey and using foot print map of previous academic study of same study ward. The building structural classification of study area was not available to the researcher. The building structural classification was taken from the HAZUS for most representative buildings in study area.

- d) The damage functions i.e. fragility curve is based on two types of curves known as capacity curve and demand curve. The data requires for generating demand curve is mentioned in section b. The demand curve has been generated from the data taken from an academic research. The capacity curve requires the design parameters of the building. The design parameters like response of structural elements were not available for the representative buildings. The researchers took the parameters to generate capacity curve from HAZUS.
- e) The fragility curve is characterized by median value of peak building response and lognormal standard deviation of spectral displacement of damage state. Median values of structural component are based on building drift ratios that describe the threshold of damage state. Lognormal standard deviation describes the variability of fragility curves. Lognormal standard deviations are developed for each damage state of structural components. The variability of building response depends jointly on demand and capacity curve. These parameters are not available for representative buildings (framed and masonry) in study area. These parameters can only be generated when design parameters of building are known.

Q 2.2 What are the limitations of using the HAZUS model as an earthquake risk assessment tool for assessing risk for buildings in Dehradun city?

The limitations of using the HAZUS model in Dehradun city can be listed as below.

The HAZUS method requires carrying out comprehensive engineering analysis considering the nature of potential ground motion and the non-linear behavior of the structural components. This method is highly specialized and only field experts are capable of performing this task.

The HAZUS methodology defines the structural properties of buildings, which are based on the local construction practice and local building material available in United States. The structural properties of HAZUS model building types are different from the structural properties of representative buildings present in the study ward. For example, the structural components of Reinforced Masonry (RM) model building type are composed of concrete framing. Where as in Indian context, the structural framing is generally composed of RCC framing. The difference in structural properties greatly affects the strength of structure. Moreover the structural parameters considered in this research, for most representative buildings in study area, were taken from the HAZUS. This could be one of the reasons of getting absurd result of damage assessment of buildings in study area. The result could have been improved by collecting the structural parameters of representative buildings present in the study ward.

The HAZUS methodology requires a large amount of structural data and complex structural calculations to develop structural parameters of buildings. It is very difficult to collect structural information without involvement of expert in field. In few cases, it is difficult to assign an occupancy class to a building in study area on the basis of HAZUS building occupancy classification. The study area contains number of classes, which are not specified in HAZUS building occupancy classes. For example residential combined with commercial, religious combined with residential or educational. In the absence of these classes in classification a reliable building inventory cannot be made.

It is also very difficult to group the buildings into one particular class due to variation in structural properties of the buildings in study area. The HAZUS defines five type of structural framing such as wood frame, steel frame, concrete frame, RCC frame and masonry frame. The study area contains the building, which have more that one structural frame defined in HAZUS. For example, some building in study area have masonry vertical framing and steel horizontal framing. The non-availability of vulnerability curves of representative buildings required for calculating damage probabilities is one of the major limitations of using HAZUS in study area. In all these mentioned limitations, it is very difficult to run the HAZUS model with available data of Dehradun. To run the HAZUS model in the study area a complete structural as well as occupancy classification of most representative buildings has to be developed.

Objective 3.

To evaluate the HAZUS Building Inventory Classification (BIC) in Dehradun city that can practically be used for HAZUS based ERA in Dehradun.

Q 3.1 What information is needed and what can be collected for the classification of buildings for earthquake risk assessment in Dehradun city?

The building inventory classification consists of a two-dimensional matrix. It is based on building occupancy type and building structure type. The building occupancy classification requires information about the general occupancy and specific occupancy. The general occupancy includes the major occupancy in the study area such as residential, commercial, educational etc. The specific occupancy includes the occupancy such as independent housing, group housing, hostel, hotels etc. that comes in the general occupancy (residential occupancy). The occupancy information of each building on each floor should be required to make the building occupancy type classification in study area. The information about general occupancy is easy to collect in study area. The information about specific occupancy takes lots of time and manpower. The only way of collecting this information is the household survey.

The building structure type classification requires information about structural properties of the building. The structural properties include the structural framing and wall characteristics of the building. It also requires the response of structural elements in seismic event. The response or structural behavior of building is based on the engineering design parameters and requires the engineering computation. The design parameters can only be known if structural drawings of building are available. The structural properties can only be collected by extensive field survey of building. It also requires the involvement of field expert to collect the structural information.

Q 3.2 How best can the US-based Building Inventory Classification (BIC) be adopted for ERA for building structures in Dehradun?

The HAZUS based BIC can be adopted in Dehradun city for ERA for building structure after doing some modifications in the defining the occupancy and structural properties of model building types. The occupancy classification can be adopted by introducing the mixed classes in the occupancy classification. For example, the residential occupancy combined with commercial occupancy is very prevalent in study area. This mixed class should be added in the classification. Similarly, the religious combined with education or residential can be added in the classification.

The building structural classification can be adopted by modifying the structural properties of the model building types in HAZUS. The two model building types are RM and URM, which resemble most with the existing building types (framed and masonry) in the study ward. The RM class has similar structural characteristics with framed structure type building exist in study ward. The structural property of RM class includes the concrete framing of structural elements, whereas the structural elements in framed structure are composed of reinforced concrete. There is also a difference in casting the concrete in structural elements. This class can be used in study ward if RCC can be used in the construction of structural elements of the building and cast-in-sit concrete is used instead of pre cast concrete. The URM class has same structural properties with URM structure exist in the study ward. The URM class can be used if diaphragm is constructed of RCC concretes.

Objective 4.

To map building structures in a sample area of Dehradun city and evaluate the risk using HAZUS building classification with possible modifications based on identified parameters and analyze the applicability of HAZUS model in Dehradun city.

Q 4.1 What modifications are needed in terms of parameters to adopt HAZUS model for ERA for buildings in Dehradun city?

In chapter 6, the result of damage probability calculated by HAZUS method seems not to be very accurate. The method does not give very realistic results for earthquake risk evaluation in study ward. The method gives good results at the broad level risk evaluation i.e. between RM2 and URM model building class. The result shows the unreinforced structures are more vulnerable than reinforced structures to earthquakes. The reinforcement in the structural components can significantly improve the resistance of the building to seismic loads and energy dissipation capacity of the structure. The statement proves that the RM structures should perform better than URM structures in the seismic events. Which is also the result of the risk assessment of buildings in study area. The results seem not to be very accurate for fine level risk evaluation i.e. between URML and URMM model building class.

In general the vulnerability of the building is directly proportional to the height of the building. It means the high-rise building is more vulnerable to earthquakes than low-rise buildings. Which is in contrast to the result of the risk assessment of buildings in study area. The results shows the mid rise URM building is less vulnerable to low rise URM building in study area. Similarly low rise RM2L model class in study area is at high risk than mid rise RM2M model class. The absurd result in both the classes indicates the method is not successful for fine level ERA of building in study area. It shows the need of modifications required in terms of parameters in HAZUS to adopt in study area.

The modification needed to adopt the HAZUS methodology in Dehradun city is redefining the HAZUS model building types based on their structural properties. There are few structures, which cannot be categorized under any class of HAZUS based model building types. For example load-bearing structure with reinforced wall. The five types of building frames used in the HAZUS methodology namely wood frame, steel frame, concrete frame, RCC frame and masonry frame. Most of the structures exist in study area comes under RCC frame and masonry frame. The model building types comes under these frames are RM and URM. There is need to redefine these model building types to match the structural properties with existing building structures in study ward and calculate the structural parameters of most representative buildings to generate the vulnerability curves of these buildings.

The other modification needed to adopt the HAZUS methodology in Dehradun city is redefining the HAZUS based occupancy classes for making building inventory. The building occupancy classification mentioned in National Building Code (NBC), India is given in the annexure 6. The NBC divided the building occupancy classification into 10 categorize. These include assembly buildings, business buildings, office buildings, educational buildings, industrial buildings, institutional buildings, mercantile buildings, residential buildings, dwellings, and storage buildings. Few mixed classes should be defined in the HAZUS building occupancy classes like residential combined with commercial, religious combined with residential.

7.2. Recommendations

The HAZUS methodology can be adopted and implemented in India. The collective effort is required from various government and non-government organisations in the field of developing vulnerability functions of building. The involvement of structural expertise is very necessary in this type of research. The structural organizations should be consulted properly and technical help should be assured from these organizations to carry out research..

The effort should be made to collect the building information using advanced technology for ERA such as remote sensing and GIS. The building foot print map prepared from remote sensing image will be a very useful data for doing field survey. The building foot print map and road map can effectively reduces the time for collecting building information. The GIS can help in handling of spatial data and making number of damage scenarios for hypothetical earthquake in Dehradun.

The generation of reliable building inventory based on structural and occupancy information is one of the most difficult part of HAZUS methodology. This is the most time consuming part of the whole process. It takes months to collect and generate building data from the field. Moreover to collect the structural information of all the buildings in study ward is not possible. The effort should be made by field expert to collect the structural information of most representative buildings in the study ward and calculate all the structural parameters required for developing vulnerability functions.

The risk evaluation by HAZUS method requires large amount of building data for building risk assessment. The HAZUS method uses a building inventory based on ATC 21 data collection form. The database required for generating a building inventory was difficult to collect in short period of research. It is also very difficult to collect all the information given in this form for existing structures in study area due to non-availability of building plans. A simplified method should be adopted to collect the building information from field.

The involvement of agencies like GSI, IMD, and CBRI in earthquake risk reduction can effectively work in this area and develop HAZUS INDIA. The attempt made by researcher to make HAZUS INDIA is not fully success. The limitations of running HAZUS with Dehradun data can be overcome by collecting all the information described above. The HAZUS requires large building data and complex structural calculations.

7.3. Further Research

The database created and information collected to use HAZUS can be incorporated in further research for ERA in study area. The identified parameters, which could not be collected in this short period of research, can be collected in further research and results can be analyze again for same study area. The results can be more accurate if further studies focus on the systematic collection on structural parameters of representative buildings present in the ward. However, if other studies will be carried out in the future, the research should include the technical support from structural organizations.

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Appendix

Appendix 1: Data Collection form used in this research for field survey of study ward

Building ID				
Occupancy Class	Res, Com, Res+Com, Rel, Gov, Edu, Utility			
Occupancy Type	Single familly, Multiple family etc. (Appendix 4)			
Occupancy Label	Res1, Res2, Res3, Res4, etc (Appendix 4)			
Building Shape	Symmetrical/ Asymmetrical			
Structure Type	Framed/ Masonry			
Direct Load Path	Direct/ Indirect			
Wall Material	Brick/ Concrete/ other			
Roof Material	RCC, RBC, CGI, others			
Roof Type	Flat/ Sloping			
Plan	Regular/ Irregular			
Height/Base	>1, 1, <1			
Soft Storey	Yes/ No			
Floor Height	Equal/ Unequal			
Proximity	< 0.5m, 0.5m - 1.0m, >1.0m			
Height	Low rise (G & G+1) / Mid rise (G+2 – G+4)			
Maintenance	Good, Moderate, Poor			
Construction Age	Old (Before 1950), medium (1950-1975), new (After 1975)			
Earthquake Resistance	Yes/ No			
Setback	Yes/ No			
Front Road Width	2.4m, 3.0m, 4.0m, 6.0m, 9.0m			

Appendix 2a: Data Collection form used in SHRM project for field survey of Jabalpur city Source: Central Building Research Institute, Roorkee, India

Microzone No. IDENTIFICAION DATA	46 : DESILVA
Name Of The Owner/Occupant:	sn. Rooplal Kanda
2. House No.:	582
3. Locality / Address:	Nagier Town, Disilva ward, JABAL PUR
4. Approx. Age of Building:	1991
5. Building Usage:	Residential / Commercial / Mixed / Office / Hospital / School / Government / Factory / Historical / Others (Specify)

CONFIGURATION & SPECIFICATION

Geometry:							
6. TYPE OF BUILDING :	REINFORCED CONCRETE (WITH INFILL MASONRY WALLS) MASONRY BUILDING (CEMENT MORTAR) MASONRY BUILDING (MUD MORTAR) RR MASONRY BUILDING WOODEN BUILDING BAMBOO BUILDING OTHERS (PL. SPECIFY): MSK CLASSIFICATION: TYPE A / TYPE B / TYPE C						
7. Type of Construction:	Eramed / Load Bearing / Combination						
8. Orientation of Building w.r.t.longer direction	N- 2						
9. Number of Storey:	G	+1			<u> </u>		T
Storey Height (m)	Basement	Gr. F.	1st F	2 nd F	3rd F	4 th F	Total Ht.
	-	3.3m	3.3m				6.6m
10. Outer Dimension (m):	Length :	13 · 0	m'	Wid	th :	8.0) m
11. Built-up Area (sqm):	Length:	13.0	m	Wid	th :	8.2) m
12. Floor Area (sqm)	Basement	Gr. F.	1st F.	2 nd F.	3rd F.	4th F.	Total
	_	104 m	94m2	_		1-	198 m²
13. Line plan of building	Please draw at the blank page at the back of data-sheet with full details.						
14. Plan Configuration: (Pl.draw a layout)	Rectangula	r / L-Shap	e / U-Sha	pe / Cros	s / H-Sha	pe / Othe	ers

Appendix 2b: Data Collection form used in SHRM project for field survey of Jabalpur city

15. FOUNDATION / PLINTH	
Type of Soil	Black Cotton / Stiff Rocky Soil / Silty Sandy Soil / Hard Rock / Soft Soil
Depth of Water Table during rainy season	3.0 M
Type of Footing	Pile / Raft / Isolated Column / Wall Footing / Other (pl. specify)
Depth of Footing	1.0 M
Type of Material	Concrete / Brick Masonry / Stone Masonry / Other
Height of Plinth (above GL)	0.4 M
16. Walling (Pl. sketch the details	of opening of external walls on the blank page at the back of data-sheet)
Main Wall	Thickness: 23cm Height: 330cm Material: 8-19 Mortar Ratio: : 6
Partition Wall	Thickness: 23 cm Height: 330 cm Material: 8- M Mortar Ratio: 1:6
Lintel Not Provided.	Thickness: - cm Width: cm Material: Mortar Ratio:
Openings details	Opening Dimensions(m): Total Length: — m Door's — 0.9 x 2.2 m Wundows - 1.4 x 0.95 m
Approx. % of opening (Lopening / L)	External Walls: 30 % Internal Walls: 45 % Longer 30%; Shorter 40%
	g on main walls with position of openings from corners.
or Say	13.07
Plaster 8.0 m	Yes / No Thickness: 20 mm Material: Cement / Mortar Ratio: 1:8
Approx.% of openings G F	External Walls: 35 % Internal Walls: 50 %
Approx.% of openings FF	External Walls: 35 % Internal Walls: 50 %
GABLE WALL Whether Gable Walls are provided with some earthquake remedial measures	Yes / No — Thickness: — mm Material: — Length: — m Height: — m Yes / No —

Source: Central Building Research Institute, Roorkee, India

Appendix 2c : Data Collection form used in SHRM project for field survey of Jabalpur city Source: Central Building Research Institute, Roorkee, India

Presence of cracks in walls (if	Crack type : Stru	ctural / Non-structu	ral	
any, pl. draw line sketch, and	Grade: 1 / 2 / 3			
specify location)	- Minor cracks in Partition walls of 1-3mm wide			
	2011 1430 150	g of plasten	at few pl	aces
17. Column	Breadth: — n	nm Depth: —	mm Material: -	6 mills
Cracks (if any, pl. draw a line sketch, and specify location)	440 000 00 00 00 00 00 00	ctural / Non-structur	ral	
	Grade: 1 / 2 / 3	3		
Corrosion (if any, extent) (Pl.specify type of reinforcement : MS/HYSD)	-			
Spalling of Concrete (if any, extent)	-			
18. Beam		Breadth (mm)	Depth (mm)	Span (m)
	Primary Beam	230	200	3.5
S	Secondary Beam	230	200	3.0
Cracks (if any, pl. draw a line sketch, and specify location)	Crack type: Structural / Non-structural			
<i>#</i>		-		
Corrosion (if any, extent)				
(Pl.specify type of reinforcement : MS/HYSD)	1			
Spalling of Concrete (if any, extent)				
19. Slab	Thickness: 125	mm Material:	Cement Conc	retc .
Cracks (if any, extent)	Grade: 1 2 /			3.9
Corrosion (if any, extent) (Pl.specify type of reinforcement : MS/HYSD)	YES, SPa	Mage of co	novete covi	~
Spalling of Concrete (if any, extent)		1		81 81 81 81

Appendix 2d : Data Collection form used in SHRM project for field survey of Jabalpur city Source: Central Building Research Institute, Roorkee, India

20. Roof	Pitched		Flat			
	Tiles:		RCC 130 mm th.			
	Slate:	_		RBC	_	
	GI/AC Sheets	_		Any othe	r: —	
	Any Other:	Any Other:		Pl. draw det	tails of pitched ro	oof:
		Width,	Depth,		-	_
	Ridge Rafter	-	-	7		
	Rafter	_	_			
	Purlin	-	_	7		
	Cladding	-	-	7		
	Type of wood	Dewi	DAR			
	Decay due to termites / insects					to
21. Staircase						
Slab	Thickness: (30	mm	Width:	100	mm
Beam	Width: 2	230	mm	Depth:	200	mm
Material of construction:	Concrete / Brick N	dasonry				
Mumty Details	Height (m): Plan Dimension (m	_ 1) _	Suppor	rt Details:	_	
Any other information:	_	₹\$#\$5 ~}#				
22. Corner Reinforcement	Yes / No (if yes,	Type of Re	ein: —	Dia	of Rein.: -	— mm)
23 Provision of Plinth Band	Yes / No (if yes, 'Location:	VOIDA DO ANTO		Thickness:	— mr	n)
24 Provision of Lintel Band	Yes / No (If yes, Width: mm Thickness: mm) Location:			n)		
25 Provision of Roof Band (In case of pitched roof)	Yes / No (if yes, Width: — mm Thickness: mm) Location: —					
26 Provision of Gable Band (in case of pitched roof)	Yes / No (if yes, 'Location: —	Width: –	— mm	Thickness:	— mr	n)
27. Overall Quality of Construction	Low / Mediun	n / High				
28. Quality of construction						
Joints:	Poor jou					
Quality of Bricks	Medium	1 (53	35 K9	1cm2)	comp. 5	Kength
Verticality / Plumb	0. K	-	7			,

Appendix 2e : Data Collection form used in SHRM project for field survey of Jabalpur city Source: Central Building Research Institute, Roorkee, India

29. Overhead Water Tank	Capacity: — Placement Details(like	cum Material of WT : Co support, location etc.) —	ncrete / Brick Mas/Plastic -
30. Qualitative Assessment of	Column	Beam	Slab
Concrete (Results obtained through Rebound Hammer Test)		12 N/mm2	18 N/mm2
	—	12 N/mm2	16 N/mm2
	-	14 N/mm 2	16 N/mm2

CONDITION OF STRUCTURE & AMBIENCE

31. SETTLEMENT CRACKS IN FLOOR	YES / NO
32. Water logging	Xes / No
33. Wall/Column out-of-plumb	Yés / No
34. Cracks in Walls	Yes/Nov Minor cracks in walls
35. Dampness	Xes/No
36. Excessive Cantilevered portion (> 90 cm)	Yes/No 1: 20 m cantilever of balcony
37. Proximity to Taals	Yes/ No
38. Surrounding Environment of Building	- connected adjoining bldgs. - Difference in Slab/ Hour level.

Scenario of Distress in Non-Structural Components

39. ADDITIONAL EXCESSIVE LOADING	XES / NO
40. Cladding / Glazing	YES / No
41. Mounting	Xes / No
42. Corbel etc	YES / No
43. Ceiling / False Roof	YES / No
44 Interior Decoration	Yes / No
45 Parapets	Yes / No Height: 75 cm, Thickness: 115 mm
46.Storage Racks / Book-Shelve	xes/No RC ornamental.
47. Veneer	Xes/No

C VULNERABILITY PARAMETERS

48. SEISMIC LOAD PATH	YES / NOH	
49. Vertical Discontinuity	Yes / No	
50. Soft Story	Yes / No	
51. Setback	Yes / No	
52. Offset	Yes / No	
53 Resistance Element	Yes/ No	
54 Plan Discontinuity	Yes / No	
55 Adjacency / Pounding	Yes /_No	

Appendix 3: Organizations and Institute visited in field survey

Source: Field survey

Organisation Name/ Institute Name	Address	Department Name	Contact Person	Data Collection, Discussion
Indian Institute of Technology (IIT)	IIT Roorkee campus, Roorkee, Uttaranchal- 247 667 http://www.rurkiu.ernet.in Tel. – 0091 1332 285128 dayasfeq@iitr.ernet.in	Department of Earthquake Engineering (DEQ)	Dr. Daya Shanker	Earthquake Data
Indian Institute of Technology (IIT)	IIT Roorkee campus, Roorkee, Uttaranchal- 247 667 http://www.rurkiu.ernet.in Tel0091 0133 2285042 yogendrafeq@iitr.ernet.in	Department of Earthquake Engineering	Dr. Yogendra Singh	Building Class & HAZUS applicability
Indian Institute of Technology (IIT)	IIT Roorkee campus, Roorkee, Uttaranchal- 247 667 http://www.rurkiu.ernet.in Tel. – 0091 0133 285566	Earth Science Department	Dr. AK Pachauri	Ground motion and earthquake data
Indian Institute of Technology (IIT)	IIT Roorkee campus, Roorkee, Uttaranchal- 247 667	Structural Engineering Division	Dr. Achal Mittal	Building Classification
Central Building Research Institute (CBRI)	IIT Roorkee campus, Rookie, Uttaranchal- 247 667 Tel. – 0091 0133 283349 agrawal_shaileshkr@yahoo.com	Disaster Management Cell	Dr. Shailesh Agrawal	Indian model & Building Classification
Indian Meteorological Department (IMD)	Mausam Bhawan, Lodhi Road, New Delhi-110003 http://www.imd.ernet.in/	Earthquake Risk and Evaluation Center (EREC)	Dr. PS Mishra	Indian Model for seismic microzonation
Building Material and Technological Promotion Council (BMTPC)	Core 5 -A, First Floor, India Habitat Centre, Lodi Road New Delhi- 110 003, Tel. 91-11-24638096, E-mail: info@bmtpc.org www.bmtpc.org			Literature and research papers
National Institute of Disaster Management (NIDM), (Ministry of Home Affairs)	I.P. Estate, Ring Road New Delhi - 110002 Tel.Fax: 91-11-23702442 http://www.nidm.net/		Dr. Amir Ali Khan	Literature and research papers
Bureau of Indian Standards (BIS), Manak Bhavan	9 Bahadur Shah Zafar Marg New Delhi 110 002, India Tel: 23230131,Fax: 23234062, info@bis.org.in, www.bis.org.in			Indian standard for earthquake resistance buildings & NBC
National Information Centre of Earthquake Engineering, (NICEE)	Department of Civil Engineering Indian Institute of Technology Kanpur, 208016, Tel: 91-0512- 2597866, http://www.nicee.org	Not Visited	Not Visited	Not Visited

Appendix 4: Building Occupancy classification of HAZUS

Label	Occupancy Class	Example Descriptions
	Residential	
RES1	Single Family Dwelling	Independent Houses, Flats
RES2	Mobile Home	Mobile Home
RES3	Multi Family Dwelling	Apartment/ Condominium
RES4	Temporary Lodging	Hotel/ Motel
RES5	Institutional Dormitory	Group Housing
RES6	Nursing Home	
	Commercial	
COM1	Retail Trade	Store
COM2	Wholesale Trade	Warehouse
СОМЗ	Personal and Repair Service	Service Station/ Shop
COM4	Professional/ Technical Service	Offices
COM5	Banks	
COM6	Hospital	
COM7	Medical Office/ Clinic	
COM8	Entertainment & Recreation	Restaurants/ Bars
COM9	Theatres	Theatres
COM10	Parking	Garages
	Industrial	
IND1	Heavy	Factory
IND2	Light	Factory
IND3	Food/ Drugs/ Chemicals	Factory
IND4	Metals/ Mineral Processing	Factory
IND5	High Technology	Factory
IND6	Construction	Offices
	Agriculture	
AGR1	Agriculture	
	Religion	
REL1	Church/ Non Profit	
	Government	
GOV1	General Service	Office
GOV2	Emergency Response	Police/ Fire Station
	Education	
EDU1	Grade School	
EDU2	College/ Universities	Does not include group housing

Appendix 5: Building occupancy classification

Source: National Building Code, India

Label	Occupancy Class	Example Description
1	Residential	Apartments, restaurants, dormitories, and residential hotels.
2	Dwellings	Flats, Independent houses.
3	Office	Offices, commercial complex.
4	Mercantile	Office, service facility.
5	Business	Banks, professional establishments, courthouses, and libraries.
6	Educational	Schools, colleges.
7	Institutional	Hospitals, sanitaria, custodial, prisons and reformatories.
8	Assembly	Theatres, motion picture houses, assembly halls, city halls, marriage Halls, town Halls, auditoria, exhibition halls, museums, skating rings, gymnasium, restaurants, places of worships, dance halls, club rooms, passenger stations and terminals of air, recreation stadium.
9	Industrial	Assembly plant, power plants, refineries, gas plants, mills dairies, factories.
10	Storage	Garages, hangers, truck terminals, grain elevators, barns and stables.

Appendix 6: Structural description of HAZUS model building types

Model	Label	Model Name		H	leight	
No			Range	Stories	Stories	Height (ft)
31	RM2L	Reinforced Masonry Bearing Wall	Low Rise	1-3	2	20
32	RM2M	with Precast Concrete Diaphragms	Mid Rise	4-7	5	50
		Clas	s Descripti	on		
		These buildings have bearing walls a wall structures with wood or metal of composed of pre cast concrete elements are steel or concrete (cast-in-place or often have a cast-in-place topping.	deck diaph ments such supported	ragms, bu n as plank on interio	t the roof s or tee-b r beams a	and floors are eams and the nd columns of
Model	Label	Model Name		F	leight	
No			Range	Stories	Stories	Height (ft)
34	URML	Unreinforced Masonry Bearing	Low Rise	1-2	1	15
35	URMM	Walls	Mid Rise	3+	3	35
		Clas	s Descripti	on		
		Class Description These buildings include structural elements that vary depending on the building's age and, to a lesser extent, its geographic location. In buildings built before 1900, the majority of floor and roof construction consists of wood sheathing supported by wood framing. In large multistory buildings, the floors are cast-in-place concrete supported by the unreinforced masonry walls and/or steel or concrete interior framing. In unreinforced masonry constructed after 1950 (outside California) wood floors usually have plywood rather than board sheathing. In regions of lower seismicity, buildings of this type constructed more recently can include floor and roof framing that consists of metal deck and concrete fill supported by steel framing elements. The perimeter walls, and possibly some interior walls, are unreinforced masonry. The walls may or may not be anchored to the diaphragms. Ties between the walls and diaphragms are more common for the bearing walls than for walls that are parallel to the floor framing. Roof ties usually are less common and more erratically spaced than those at the floor levels. Interior partitions that interconnect the floors and roof can reduce		it before 1900, along supported cast-in-place el or concrete 1950 (outside sheathing. In the recently can be concrete fill consibly some to be anchored the common for along. Roof ties the at the floor		

Appendix 7: Description of damage states of RM2 model building type in HAZUS Source: HAZUS Manual

C	lassification of structural damage to RM2 model building type
Damage State	Damage Description
Slight	Diagonal hairline cracks on masonry wall surfaces; larger cracks around door and window openings in walls with large proportion of openings.
Moderate	Most wall surfaces exhibit diagonal cracks; some of the shear walls have exceeded their yield capacities indicated by larger cracks.
	In buildings with relatively large area of wall openings most shear walls have exceeded their yield capacities and some of the walls have exceeded their ultimate capacities exhibited by large, through-the wall diagonal cracks and visibly buckled wall reinforcement. The diaphragms may also exhibit cracking
	Structure is collapsed or is in imminent danger of collapse due to failure of the walls. Approximately 13%(low-rise), 10%(mid-rise) or 5%(high-rise) of the total area of RM2 buildings with complete damage is expected to be collapsed.

Appendix 8: Description of damage states of URM model building type in HAZUS Source: HAZUS Manual

С	lassification of structural damage to URM model building type
Damage State	Damage Description
Slight	Diagonal, stair-step hairline cracks on masonry wall surfaces; larger cracks around door and window openings in walls with large proportion of openings; movements of lintels; cracks at the base of parapets.
	Most wall surfaces exhibit diagonal cracks; some of the walls exhibit larger diagonal cracks; masonry walls may have visible separation from diaphragms; significant cracking of parapets; some masonry may fall from walls or parapets.
	In buildings with relatively large area of wall openings most walls have suffered extensive cracking. Some parapets and gable end walls have fallen. Beams or trusses may have moved relative to their supports.
	Structure has collapsed or is in imminent danger of collapse due to in- plane or out-of-plane failure of the walls. Approximately 15% of the total area of URM buildings with complete damage is expected to be collapsed.

Appendix 9: Model building types In HAZUS

	1		Height				
No. Label Desc		Description	scription Ra		Турі	cal	
			Name	Stories	Stories	Feet	
1	W1	Wood, Light Frame (≤ 5,000 sq. ft.)		1 - 2	1	14	
2	W2	Wood, Commercial and Industrial (> 5,000 sq. ft.)		All	2	24	
3	S1L	Steel Moment Frame	Low-Rise	1 - 3	2	24	
4	S1M		Mid-Rise	4 - 7	5	60	
5	S1H		High-Rise	8+	13	156	
6	S2L	Steel Braced Frame	Low-Rise	1 - 3	2	24	
7	S2M		Mid-Rise	4 - 7	5	60	
8	S2H		High-Rise	8+	13	156	
9	S3	Steel Light Frame		All	1	15	
10	S4L	Steel Frame with Cast-in-Place Concrete	Low-Rise	1-3	2	24	
11	S4M	Shear Walls	Mid-Rise	4 - 7	5	60	
12	S4H		High-Rise	8+	13	156	
13	S5L	Steel Frame with Unreinforced Masonry	Low-Rise	1 - 3	2	24	
14	S5M	Infill Walls	Mid-Rise	4 - 7	5	60	
15	S5H	PORTO CAR INVESTO CO.	High-Rise	8+	13	156	
it beset in	f	COMMUNICATION OF THE PROPERTY AND A STATE OF THE PROPERTY		Town and	207	7	
16	C1L	Concrete Moment Frame	Low-Rise	1 – 3	2	20	
17	C1M		Mid-Rise	4 - 7	5	50	
18	C1H		High-Rise	8+	12	120	
19	C2L	Concrete Shear Walls	Low-Rise	1 - 3	2	20	
20	C2M		Mid-Rise	4 - 7	5	50	
21	C2H		High-Rise	8+	12	120	
22	C3L	Concrete Frame with Unreinforced	Low-Rise	1 - 3	2	20	
23	C3M	Masonry Infill Walls	Mid-Rise	4 - 7	5	50	
24	C3H		High-Rise	8+	12	120	
25	PC1	Precast Concrete Tilt-Up Walls		All	1	15	
26	PC2L	Precast Concrete Frames with Concrete	Low-Rise	1 - 3	2	20	
27	PC2M	Shear Walls	Mid-Rise	4 - 7	5	50	
28	PC2H		High-Rise	8+	12	120	
29	RM1L	Reinforced Masonry Bearing Walls with	Low-Rise	1-3	2	20	
30	RM1M	Wood or Metal Deck Diaphragms	Mid-Rise	4+	5	50	
31	RM2L	Reinforced Masonry Bearing Walls with	Low-Rise	1 - 3	2	20	
32	RM2M	Precast Concrete Diaphragms	Mid-Rise	4 - 7	5	50	
33	RM2H	99477 80111	High-Rise	8+	12	120	
34	URML	Unreinforced Masonry Bearing Walls	Low-Rise	1 - 2	1	15	
35	URMM		Mid-Rise	3+	3	35	
36	мн	Mobile Homes		All	1	10	

Appendix 10: Fragility curve parameters of low design code

Buile	Building Properties	orthes		Interst	Interstory Drift at				Sp	Spectral Displacement (mches)	lacement (u	nches)		
Type	Height	Height (inches)	2	Threshold o	Threshold of Damage State	ar	SII	Slight	Mo	Moderate	Ext	Extensive	Con	Complete
	Roof	Modal	Silgh	Moderate	Extrensive	Complete	Median	Beta	Median	Beta	Median	Beta	Median	Beta
WI	168	126	0.0040	0.0099	0.0306	05/00	0.50	0.93	1.25	0.98	3.86		9.45	0.00
W2	288	216	0.0040	0.0099	0.0306	0.0750	98.0	0.97	2.14	060	6.62	0.89	16.20	0.00
SIL	288	216	09000	960000	0.0203	0.0500	130	0.77	2.07	0.78	4.38	92.0	10.80	96'0
SIM	720	540	0.0040	0.0064	0.0135	0.0333	2.16	89.0	3.4	0.78	7.30	0.85	18.00	0.98
SIH	1872	1123	0.0030	0.0048	1010.0	0.0250	3.37	99'0	5.37	0.70	11.38	0.76	28.08	0.92
S2L	288	216	0.0050	03000	0.0200	0.050.0	1.08	96'0	1.73	0.89	4.32	0.86	10.80	86.0
SZM	720	540	0.0033	0.0053	0.0133	0.0333	1.80	0.70	2.88	63	720	0.85	18.00	0.98
S2H	1872	1123	0.0025	0.0040	0.0100	0.0250	2.81	0.66	4.49	0.67	11.23	0.74	28.08	0.92
53	180	135	0.0040	0.0064	0.0161	0.0438	0.54	360	0.87	0.99	2.17	1.01	5.91	06.0
4L	288	216	0.0040	0.0064	1910'0	0.0438	98.0	1.05	1.38	86.0	3.47	0.89	9.45	86.0
4M	027	540	0.0027	0.0043	0.0107	0.0292	144	0.76	2.31	0.78	5.78	06'0	15.75	660
4H	1872	1123	0.0020	0.0032	0.0000	0.0219	2.25	0.70	3.60	0.75	10.6	06'0	24.57	860
SL SL	288	216	0.0030	09000	0.0150	0.0350	0.65	H	1.30	1.04	3.24	66.0	1.56	0.95
SM	720	540	0.0020	0.0040	0.0100	0.0233	1.08	0.77	2.16	0.79	5.40	0.87	12.60	860
HS.	1872	1123	0.0015	0.0030	0.0075	0.0175	1.68	0.70	3.37	0.73	8.42	0.89	19.66	0.97
TI	240	180	0.0050	03000	0.0200	0.0500	060	0.95	1.4	16.0	3.60	0.85	00.6	26'0
IM	009	450	0.0033	0.0053	0.0133	0.0333	1.50	0.70	2.40	0.74	9009	0.86	15.00	0.98
H	1440	864	0.0025	0.0040	00100	0.0250	2.16	0.70	3.46	0.81	\$.64	0.39	21.60	0.98
21	240	180	0.0040	9/00/0	0.0197	0.0500	0.72	1.04	137	1.02	3.55	0.99	00.6	0.95
2M	900	450	0.0027	0.0051	0.0132	0.0333	1.20	0.82	2.29	0.81	5.92	0.81	15.00	66.0
JH.	1440	864	0.0020	0.0038	6600.0	0.0250	1.73	89.0	3.30	0.73	8.53	0.84	21.60	0.95
31	240	180	0.0030	0.0060	0.0150	0.0350	0.54	1.09	307	1.07	2.70	1.08	6.30	0.91
SN	00:	450	0.0020	0.0040	0.0100	0.0233	050	0.85	1.80	0.83	05.4	0.0	10.50	0.98
100	1	+00	0.0013	0.0000	0.0073	0.0175	1.30	27.70	50.7	10.0	0.40	0.50	77.77	200
PC1	180	135	0.0040	0.0064	0.0161	0.0438	0.54	1.00	0.87	1.05	2.17	1.12	5.91	0.89
PC2L	240	180	0.0040	0.0064	0.0161	0.0438	0.72	1.08	1115	1.03	58	86.0	7.88	96.0
PCZM	009	450	0.0027	0.0043	0.0107	0.0292	21	0.81	1.92	6.79	25.5	0.84	13.12	0.00
H	146	t 000	0.0020	0.0052	0.0050	61700	1. (3	0.71	77.77	0.75	0.95	0.89	18.90	0.98
RMIL	95	180	0.0040	0.0064	1910.0	0.0438	225	1.11	212	1.10	280	110	7.88	0.92
MILIA	200	150	0.0021	ctorio	0.0107	2570.0	1.20	100	7.27	10.0	10.	6.75	13.12	26.5
RMEL	98	180	0.0040	00000	0.0161	0.0438	1,30	1.05	25	1.07	282	010	13.17	16.0
RACH	145	\$64	0 00 00	0.0032	0.0000	0.0219	121	0.69	2.77	120	693	0.87	18.90	960
URM	180	135	0.0030	09000	0.0150	0.0350	0.41	66'0	0.81	1.05	2.03	1.10	4.73	1.08
URMIN	420	315	0.0020	0.0040	00100	0.0233	0.63	16'0	1.26	0.92	3.15	0.87	7.35	0.91
MH	130	130	OFFICE	00000	0.0040	0.070.0	0.48	100	0.06	1.00	3 6 6	1.63	0.40	000

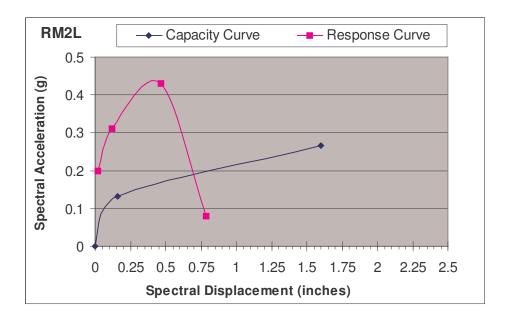
Appendix 11: Structural fragility curve parameters of RM2 and URM model building types Source: HAZUS Manual

		Struct	ural Fraç	gility Cu	rve Para	meters		
			Low	Design	Code			
	Sliç	ght	Mode	erate	Exter	nsive	Comp	olete
Туре	Median	Beta	Median	Beta	Median	Beta	Median	Beta
RM2L	0.7200	1.0500	1.1500	1.0700	2.8900	1.0900	7.8800	0.9100
RM2M	1.2000	0.8400	1.9200	0.8100	4.8100	0.7700	13.1200	0.9600
URML	0.4100	0.9900	0.8100	1.0500	2.0300	1.1000	4.7300	1.0800
URMM	0.6300	0.9100	1.2600	0.9200	3.1500	0.8700	7.3500	0.9100

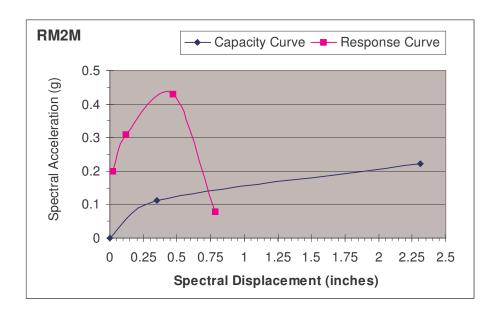
Appendix 12: Capacity curve parameters of RM2 and URM model building types Source: HAZUS Manual

	. ,		ameters for Design Level	
	Yield Capad	city Points	Ultimate Cap	acity Points
Туре	Dy (in.)	Ay (g)	Du (in)	Au (g)
RM2L	0.16	0.13	1.60	0.27
RM2M	0.35	0.11	2.31	0.22
URML	0.24 0.20 2.40 0.4			
URMM	0.27	0.11	1.81	0.22

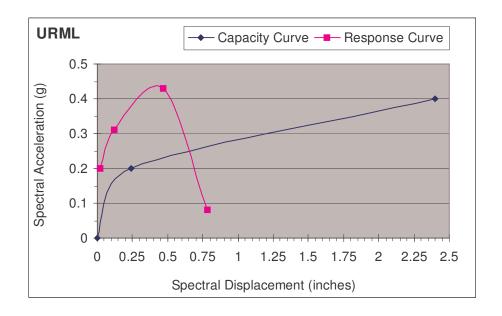
Appendix 13a: Peak building response spectra for RM2L model building type



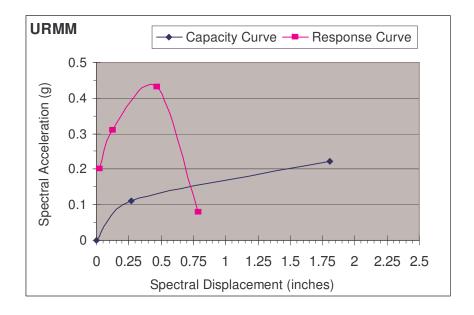
Appendix 13b: Peak building response spectra for RM2M model building type



Appendix 13c: Peak building response spectra for URML model building type



Appendix 13d: Peak building response spectra for URMM model building type



Appendix 14: Capacity curve parameters of model building types for low seismic design Source: HAZUS manual

.

Building	Yield Ca	pacity Point	Ultimate Capacity Point		
Type	D, (in.)	A, (g)	D _e (in.)	$A_{n}(g)$	
Wl	0.24	0.200	4.32	0.600	
W2	0.16	0.100	2.35	0.250	
SIL	0.15	0.062	2.29	0.187	
SIM	0.44	0.039	4.44	0.117	
SIH	1.16	0.024	8.73	0.073	
S2L	0.16	0.100	1.57	0.200	
S2M	0.61	0.083	4.04	0.167	
S2H	1.94	0.063	9.68	0.127	
\$3	0.16	0.100	1.57	0.200	
S4L	0.10	0.080	1.08	0.180	
S4M	0.27	0.067	2.05	0.150	
S4H	0.87	0.051	4.90	0.114	
SSL	0.12	0.100	1.20	0.200	
S5M	0.34	0.083	2.27	0.167	
S5H	1.09	0.063	5.45	0.127	
CIL	0.10	0.062	1.47	0.187	
CIM	0.29	0.052	2.88	0.156	
ClH	0.50	0.024	3.77	0.073	
CIL	0.12	0.100	1.50	0.250	
C2M	0.26	0.083	2.16	0.208	
C2H	0.74	0.063	4.59	0.159	
C3L	0.12	0.100	1.35	0.225	
C3M	0.26	0.083	1.95	0.188	
C3H	0.74	0.063	4.13	0.143	
PCI	0.18	0.150	1.80	0.300	
PC2L	0.12	0.100	1.20	0.200	
PC2M	0.26	0.083	1.73	0.167	
PC2H	0.74	0.063	3.67	0.127	
RMIL	0.16	0.133	1.60	0.267	
RMIM -	0.35	0.111	231	0.222	
RMOL	0.16	0.133	1.60	0.267	
RMIM	0.35	0.111	2.31	0.222	
RM2H	0.98	0.085	4.90	0.169	
URML	0.24	0.200	2.40	0.400	
URMM	0.27	0.111	1.81	0.222	
MH	0.18	0.150	2.16	0.300	

Appendix 15: Building Classification in Radius method

Source: (Villacis and Cardona, 1999)

RES1	Informal construction - mainly slums, row housing etc. made from unburned bricks, mud mortar, loosely tied walls and roofs
RES2	URM-RC composite construction - sub-standard construction, not complying with the local codal provisions. Height up to 3 stories, URM is un-reinforced brick or stone masonry, while RC is steel reinforced cement concrete construction
RES3	URM-RC composite construction - old, deteriorated construction, not complying with the latest codal provisions. Height 4 - 6 stories
RES4	Engineered RC construction - newly constructed multi-storied buildings, for residential and com- mercial (shops and offices) purposes
EDU1	School buildings, up to 2 stories. Such buildings usually constitute a very small percentage of the total building counts
EDU2	School buildings, greater than 2 stories. Such buildings usually constitute a very small percentage of the total building counts
MED1	Low to medium rise hospitals. Such buildings usually constitute a very small percentage of the total building counts
MED2	High rise hospitals. Such buildings usually constitute a very small percentage of the total building counts
COM	Shopping Centres and Shopping Malls. Such buildings usually constitute a very small percentage of the total building counts
IND	Industrial facilities, both low and high risk