URBAN SEISMIC RISK ASSESSMENT IN DEHRADUN CITY USING REMOTE SENSING AND GEOINFORMATION TECHNIQUES

Thesis submitted to the Andhra University in partial fulfillment of the requirement for the award of Master of Technology in Remote Sensing and Geographic Information System

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CERTIFICATE

This is to certify that **Miss Debarati Roy** has carried out the case study entitled **"URBAN SEISMIC RISK ASSESSMENT IN DEHRADUN CITY USING REMOTE SENSING AND GEOINFORMATION TECHNIQUES"** for the partial fulfillment for the award of M.Tech Degree in Remote Sensing and GIS of Andhra University. This has been carried out in the Human Settlement Analysis Division of Indian Institute of Remote Sensing (NRSA), Dept. of Space, Govt. of India.

The report contains the original work carried out by the trainee and has duly acknowledged the data sources and the facilities used.

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External Examiners
March 2007, Dehradun

Dedicated to my beloved parents

ABSTRACT

"Although the incidence of major natural disasters has not increased, their effects are becoming more severe in the Third World because of the growing numbers of people and structures located in hazard-prone areas. Millions of people in these expanding urban populations are potential victims of disasters of cataclysmic proportions, and even the political and economic stability of many nations in Africa, Asia and Latin America can be threatened." – Spencer W Havlick

Modern man, for all his intellectual development, his technological sophistication and even his technical abilities, is still at the mercy of natural forces. The scale and complexity of economic development makes man more and more dependent on the smooth functioning of very broad economic systems and technical facilities. Therefore, he may now not only be vulnerable to direct blows by natural disasters, but also indirectly vulnerable to catastrophes in geographically distant areas.

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. Direct relationships between the damage of civil structures such as buildings to the number of casualties have been found. 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. In India, till date, no precise risk evaluation model of earthquake risk and damage assessment has been developed. Thus, in order to reduce risk, models developed by other countries have been adopted.

The secretariat of the International Decade for Natural Disasters Reduction (IDNDR 1990-2000), United Nations, Geneva, therefore, launched the RADIUS (Risk Assessment tools for Diagnosis of Urban areas against Seismic disasters) initiative in 1996, with financial assistance from the Government of Japan. It was aimed to promote worldwide activities for reduction of seismic disasters in urban areas, particularly in developing countries. The present study has been done with an aim to use RADIUS for analyzing the life and property damage in an urban area. In doing so, mitigation measures have been planned. This thesis work had been divided in three parts. The first part tries to assess the amount of urban densification that has occurred in the area, over a span of 5 years. The second part deals with quantification of life and property damage at the various magnitude of earthquake. The third part involves mitigation measures that could be made in case of a crisis.

Urban seismic risk assessment in Dehradun city
using Remote Sensing and Geoinformation techniques.

In order to reduce the impact of disasters, government plans a complete strategy, called disaster management. While deciding on these strategies, availability of various data, like buildings, roads, population, asset, etc plays a crucial role. The majority of the data is spatial and can be mapped. With the advent of GIS technology, many limitations have been overcome and dynamic loss studies can now be performed. With the rapid urbanization that is taking place in Dehradun, vulnerability studies have become a necessity. The various parameters that have been used in this study includes building material, roof material, building type, number of stories, maintenance, building shape, utilities, facilities, day and night population, etc. Finally, amount of vulnerability related to every building has been calculated and impact of it on its population has been shown.

ACKNOWLEDGEMENT

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Debarati Roy
IIRS, Dehradun,
India.
March 2007

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1

1. Introduction

This chapter briefly introduces the problems and an issue establishing the need for the study outlines the aims and objectives of the study and henceforth details out the scope of work. It then outlines the structure of the thesis.

1.1 General Introduction

Urbanization is increasing rapidly in India and shall continue for the next few decades. Urban landscapes change over time as new urban fabric is added and also as the existing fabric is internally modified (e.g. new buildings replace old ones, plots are amalgamated or subdivided, street layouts are modified) (Knox, 1995; Cadwallader, 1996). These patterns of urban densification and internal modifications are of major concern to sustainable development because they represent the physical manifestations of a range of social, economic, cultural, and political dimensions associated with urban dynamics. With the advent of rapid urbanization, it has become extremely necessary to study vulnerability assessment of these areas.

Earthquake is one of the most destructive natural hazards of geological origin. Moreover, it can occur at any time without any warning and can destroy buildings, infrastructure and above all lead to human loss and tragedy. With the current state of scientific knowledge, it is difficult to predict when an earthquake will occur, although we know the probable regions and expected magnitude based upon seismic zonation maps. In every earthquake most of the loss of life and property are caused by the damage of the highly occupied weakest buildings located in a seismically active area. Therefore, seismic risk assessment of the population and of the buildings is the most important study to predict expected loss and help in the formulation of disaster management plans for the local authorities.

In the 20th century, well over 1000 fatal earthquakes were recorded with a cumulative loss of life estimated at 1.5 to 2.0 million (Pomonis, 1993). It has been observed that, in some areas of India have experienced large earthquakes and others have no known history of the occurrence of earthquakes. Therefore, in India, the frequent occurrence of damaging earthquakes clearly demonstrates the high seismic hazard risk and in turn highlights the need for a comprehensive earthquake disaster risk management policy (Sinha and Goyal, 2002).

Studying earthquake damage and loss estimation is a 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 (Agarwal, 2004). With the advancement of space technology, it is now possible to overcome the difficulties in evaluating the damage of urban infrastructure in a pre as well as post disaster 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 at al., 2002). Some ground surveying is done to collect damage information, which takes up quite some amount of considerable time. During this period, several ground changes occur which does not, in turn, help in the accuracy of the damage to be assessed. Database that is created in a GIS environment can be effectively used for preparation of disaster management plan of any region. A quick and effective evaluation minimizes human suffering and helps in the rescue and relief operations. The advancement of this technology helps urban planners, emergency managers, risk managers and decision makers to understand the impact of earthquakes and incorporate the results into urban development plans and mitigation program.

1.2 Relevance of Study

The Indian subcontinent is highly prone to natural disasters. As per the latest seismic zoning map brought out by the Bureau if Indian Standards (BIS), over 65% of the country id prone to earthquakes of intensity MSK VII or more. Some of the most intense earthquakes of the world have occurred in India, but fortunately, none of these have occurred in ant of the major cities. India has highly populous cities, located in zones of high seismic risk. Typically, the majority of the constructions in these cities would turn into a major disaster. It is most important in medium and long term to formulate strategies to reduce the vulnerability to and losses arising from a possible earthquake striking one of these cities. Six major earthquakes have struck different parts of India over a span of the last 15 years. The damages caused by these earthquakes reiterate the scale of vulnerability. However, if any of these earthquakes had struck populous urban centers, the damages in terms of human lives and property would have been colossal. Frequent disasters lead to erosion of development gains and restricted options for the disaster victims. Physical safety, especially that of the vulnerable groups, is routinely threatened by hazards. Disasters such as the Gujarat Earthquake have very clearly illustrated that we need mitigation, preparedness and response plans so that the threat to human life and property is minimized.

The highest seismic risk is concentrated in the north, near the border with Pakistan, Bangladesh, Bhutan, Nepal, and China. This region of high seismic risk is home to 610 million people, 60% of the nation's population, containing cities with 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. On January 26th 2001, a very severe earthquake struck Bhuj and shook most parts of Gujrat, causing widespread damage and devastation. Over 13,805 persons lost their lives, 167000 persons were injured, over million homes were damaged or destroyed and there was a large-scale damage to social and physical infrastructure. (GSDMA, 2002). The India-Pakistan earthquake on October 8th 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 epicenter was 125km WNW of Srinagar near Muzaffarabad, Kashmir. The earthquake was widely felt in Islamabad, Lahore, Punjab, Chandigarh, Delhi, Himachal Pradesh, Uttaranchal, Rajasthan, Haryana and adjoining areas. Nearly 20,000 people are feared dead in Pakistan and death toll in Jammu and Kashmir is reported to have crossed 600 with huge property loss.

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 casualties, damage and economic losses caused by earthquake result from ground motion acting upon buildings incapable of withstanding such motion (Montoya, 2002). Damage to buildings also causes a variety of secondary effects that can be greatly destructive. Lack of capacity buildings, lead to increase in risk of property loss, in developing countries. Damage to essential buildings substantially increases the rate of casualties.

Therefore, in the absence of adequate information and data required for risk assessment, it becomes difficult to assess the loss in a 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.

DATE	EPICENTRE		LOCATION	MAGNITUDE
	Lat(Deg N)	Long(Deg E)		
1819 JUN 16	23.6	68.6	KUTCH,GUJARAT	8.0
1869 JAN 10	25	93	NEAR CACHAR, ASSAM	7.5
1885 MAY 30	34.1	74.6	SOPOR, J&K	7.0
1897 JUN 12	26	91	SHILLONGPLATEAU	8.7
1905 APR 04	32.3	76.3	KANGRA, H.P	8.0
1918 JUL 08	24.5	91.0	SRIMANGAL, ASSAM	7.6
1930 JUL 02	25.8	90.2	DHUBRI, ASSAM	7.1
1934JAN 15	26.6	86.8	BIHAR-NEPALBORDER	8.3
1941 JUN 26	12.4	92.5	ANDAMAN ISLANDS	8.1
1943 OCT 23	26.8	94.0	ASSAM	7.2
1950 AUG 15	28.5	96.7	ARUNACHAL PRADESH-CHINA BORDER	8.5
1956 JUL 21	23.3	70.0	ANJAR, GUJARAT	7.0
1967 DEC 10	17.37	73.75	KOYNA, MAHARASHTRA	6.5
1975 JAN 19	32.38	78.49	KINNAUR, HP	6.2
1988 AUG 06	25.13	95.15	MANIPUR-MYANMAR BORDER	6.6
1988 AUG 21	26.72	86.63	BIHAR-NEPAL BORDER	6.4
1991 OCT 20	30.75	78.86	UTTARKASHI, UP HILLS	6.6
1993 SEP 30	18.07	76.62	LATUR-OSMANABAD, MAHARASHTRA	6.3
1997 MAY 22	23.08	80.06	JABALPUR,MP	6.0
1999 MAR 29	30.41	79.42	CHAMOLI DIST, UP	6.8
2001 JAN 26	23.40	70.28	BHUJ , GUJARAT	6.9

Source - http://www.imd.ernet.in/section/seismo/static/signif.htm

Figure 1-1. List of Major Earthquakes that have occurred in India

1.3 Problem Definition

The pressure of population in Dehradun city, expressed both in terms of absolute number of additional people every year, their distributional pattern, and their decadal growth rate of population, have resulted in several constraints in the development process, and have also resulted in unsustainable exploitation of the existing resource base. The process of urbanization in Dehradun in terms of net accretion of population, has been faster in recent decades, and coupled with changes in economic activities, have resulted in certain changes in the socio-economic structure of the population. Migration from the suburban and rural areas to the city in search of jobs has also been an important factor in shaping the socio-economic profile of the cities population. Its impact is felt in the social parameters like literacy and education.

In Dehradun city, it has been observed that the central areas are very congested with the presence of old and deteriorated buildings with very high population concentration. Decongestion is almost impossible at the heart of the city, where mainly reinforced masonry type of buildings is found with literally no space between the buildings. Maintenance is also considerably poor and thus, proper study of vulnerability of buildings is very important.

1.4 Research Questions

- How much urbanization has occurred in a span of 5 years?
- What is the impact of earthquake on various building types?
- What are the various building parameters for earthquake vulnerability assessment?
- How to locate and quantify vulnerable buildings?
- How many persons are at risk during various time of earthquake?
- What would be the effect on roads after earthquake?

1.5 Structure of the Report

The thesis constitutes of the following chapters:
Chapter 1. A general view of earthquake vulnerability assessment including a general introduction of Dehradun, problem statement, research questions and research objectives.
Chapter 2. Literature review including various methods for earthquake risk assessment and various parameters involved.
Chapter 3. Description of the study area along with methods and materials.
Chapter 4. It discusses the methods and materials used for the research.
Chapter 5. Results and discussions.
Chapter 6. Conclusions and recommendations.

Chapter 2

2. Literature Review

This chapter briefly reviews the concepts of earth and its interior, earthquake and its effect on various types of buildings, hazard, vulnerability and risk associated with this natural hazard.

2.1 The Earth and its Interior

Long time ago, a large collection of material masses coalesced to form the Earth. Large amount of heat was generated by this fusion, and slowly as the Earth cooled down, the heavier and denser materials sank to the center and the lighter ones rose to the top. The differentiated Earth consists of the *Inner Core* (radius ~1290*km*), the *Outer Core* (thickness ~2200*km*), the *Mantle* (thickness ~2900*km*) and the *Crust* (thickness ~5 to 40*km*). Figure 2-1 shows these layers. The Inner Core is solid and consists of heavy metals (*e.g.,* nickel and iron), while the Crust consists of light materials (*e.g.,* basalts and granites). The Outer Core is liquid in form and the Mantle has the ability to flow. At the Core, the temperature is estimated to be ~2500°*C*, the pressure ~4 million *atmospheres* and density ~13.5 *gm/cc*; this is in contrast to ~25°*C*, 1 *atmosphere* and 1.5 *gm/cc* on the surface of the Earth.

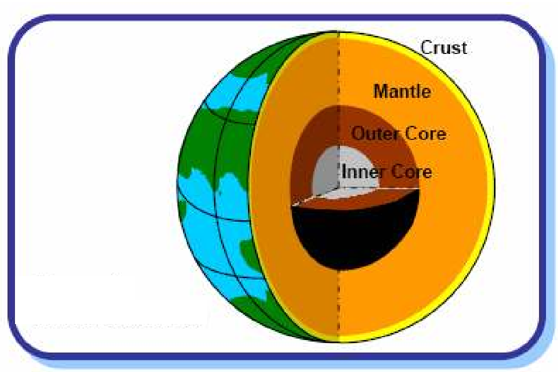


Figure 2-1. The Interior of the Earth

2.2 The Circulations

Convection currents develop in the viscous Mantle, because of prevailing high temperature and pressure gradients between the Crust and the Core, like the convective flow of water when heated in a beaker (Figure 2-2). The energy for the above circulations is derived from the heat produced from the incessant decay of radioactive elements in the rocks throughout the Earth's interior. These convection currents result in a *circulation* of the earth's mass; hot molten lava comes out and the cold rock mass goes into the Earth. The mass absorbed eventually melts under high temperature and pressure and becomes a part of the Mantle, only to come out again from another location, someday. Many such local circulations are taking place at different regions underneath the Earth's surface, leading to different portions of the Earth undergoing different directions of movements along the surface.

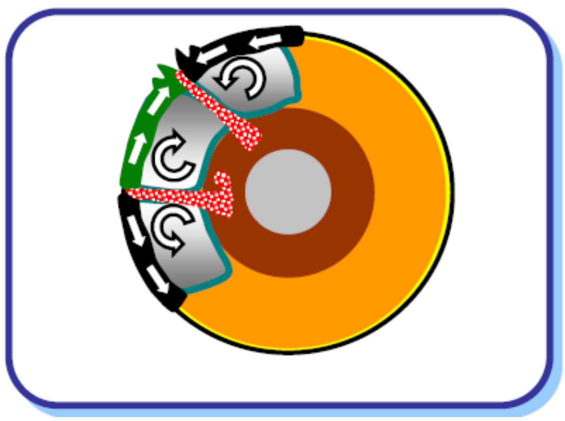


Figure 2-2. Local Convective Currents in the Mantle

2.3 Plate Tectonics

The convective flows of Mantle material cause the Crust and some portion of the Mantle, to slide on the hot molten outer core. This sliding of Earth's mass takes place in pieces called *Tectonic Plates*. The surface of the Earth consists of seven major tectonic plates and many smaller ones (Figure 2-3). These plates move in different directions and at different speeds from those of the neighboring ones. Sometimes, the plate in the front is slower; then, the plate behind it comes and collides (and *mountains* are formed). On the other hand, sometimes two plates move away from one another (and *rifts* are created). In another case, two plates move side-by-side, along the same direction or in opposite directions. These three types of inter-plate interactions are the *convergent*, *divergent* and *transform* boundaries (Figure 2-4), respectively. The convergent boundary has a peculiarity (like at the Himalayas) that sometimes neither of the colliding plates wants to sink. The relative movement of these plate boundaries varies across the Earth; on an average, it is of the order of a couple to tens of *centimeters per year*.

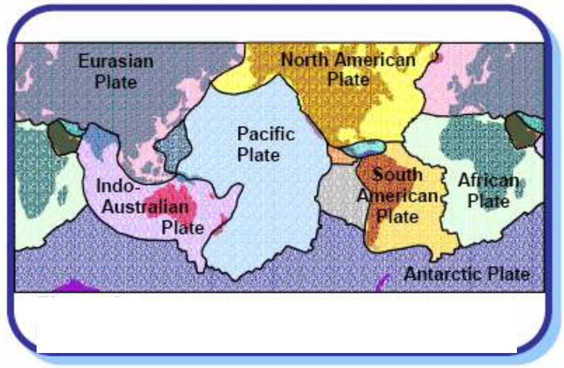


Figure 2-3. Major Tectonic Plates on the Earth's Surface

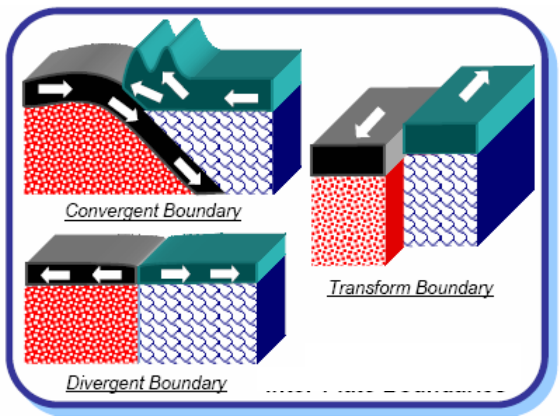


Figure 2-4. Types of Inter-Plate Boundaries

2.4 The Earthquake

Rocks are made of elastic material, and so elastic strain energy is stored in them during the deformations that occur due to the gigantic tectonic plate actions that occur in the Earth. But, the material contained in rocks is also very brittle. Thus, when the rocks along a weak region in the Earth's Crust reach their strength, a sudden movement takes place there (Figure 2-5); opposite sides of the *fault* (a crack in the rocks where movement has taken place) suddenly *slip* and release the large elastic strain energy stored in the interface rocks. For example, the energy released during the 2001 Bhuj (India) earthquake is about 400 times (or more) that released by the *1945 Atom Bomb* dropped on Hiroshima!!

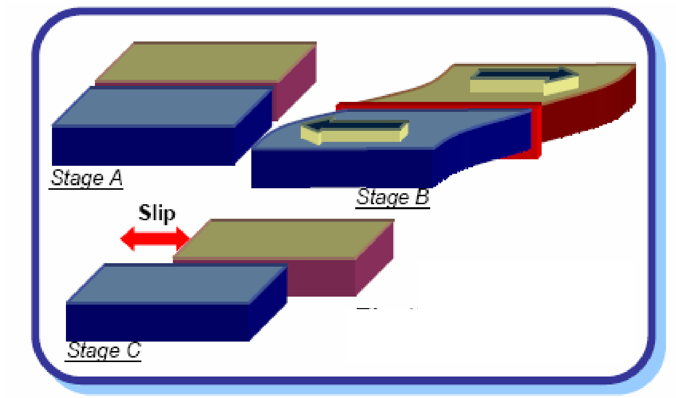


Figure 2-5. Elastic Strain Build-up and Brittle Rupture

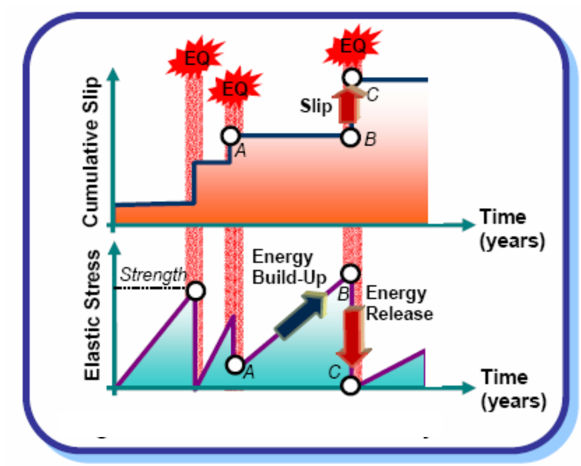


Figure 2-6. Elastic rebound Theory

The sudden slip at the fault causes *the earthquake*…. a 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. And, after the earthquake is over, the process of strain build-up at this modified interface between the rocks starts all over again (Figure 2-6). Earth scientists know this as the *Elastic Rebound Theory*. The material points at the fault over which slip occurs usually constitute an oblong three-dimensional volume, with its long dimension often running into tens of kilometers.

2.5 Seismicity and Types of Earthquakes

The distribution of earthquakes is called ***seismicity.*** Seismicity is highest along relatively narrow belts that coincide with plate boundaries. This makes sense, since plate boundaries are zones along which lithospheric plates move relative to one another. Earthquakes along these zones can be divided into shallow focus earthquakes that have focal depths less than about 100 km and deep focus earthquakes that have focal depths between 100 and 700 km.

2.5.1 Earthquakes at Diverging Plate Boundaries

Diverging plate boundaries are zones where two plates move away from each other, such as at oceanic ridges. In such areas the lithosphere is in a state of tensional stress and thus normal faults and rift valleys occur. Earthquakes that occur along such boundaries show normal fault motion, have low Richter magnitudes, and tend to be shallow focus earthquakes with focal depths less than about 20 km. Such shallow focal depths indicate that the brittle lithosphere must be relatively thin along these diverging plate boundaries. Examples - all oceanic ridges, Mid-Atlantic Ridge, East Pacific rise, and continental rift valleys such as the basin and range province of the western U.S. & the East African Rift Valley.

2.5.2 Earthquakes at Transform Fault Boundaries

Transform fault boundaries are plate boundaries where lithospheric plates slide past one another in a horizontal fashion. The San Andreas Fault of California is one of the longer transform fault boundaries known. Earthquakes along these boundaries show strike-slip motion on the faults and tend to be shallow focus earthquakes with depths usually less than about 100 km. Richter magnitudes can be large. Examples - San Andreas Fault, California, South Island of New Zealand.

2.5.3 Earthquakes at Converging Plate Boundaries

Convergent plate boundaries are boundaries where two plates run into each other. Thus, they tend to be zones where compressional stresses are active and thus reverse faults or thrust faults are common. There are two types of converging plate boundaries.
(1) Subduction boundaries, where oceanic lithosphere is pushed beneath either oceanic or continental lithosphere; and (2) collision boundaries where two plates with continental lithosphere collide. Subduction boundaries -At subduction boundaries cold oceanic lithosphere is pushed back down into the mantle where two plates converge at an oceanic trench. Because the subducted lithosphere is

cold it remains brittle as it descends and thus can fracture under the compressional stress.

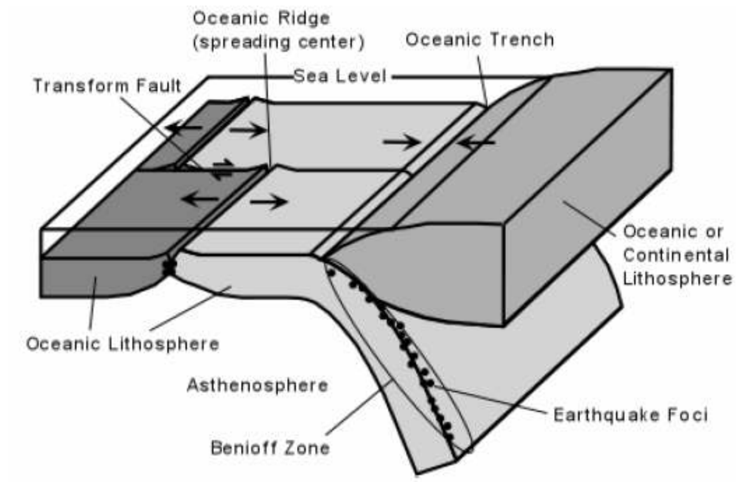


Figure 2-7. Oceanic Plate Boundary

When it fractures, it generates earthquakes that define a zone of earthquakes with increasing focal depths beneath the overriding plate. This zone of earthquakes is called the ***Benioff Zone***. Focal depths of earthquakes in the Benioff Zone can reach down to 700 km. Examples - Along coasts of South American, Central America, Mexico, Northwestern U.S., Alaska, Japan, Philippines, and Caribbean Islands.

2.5.4 Collision boundaries

At collisional boundaries two plates of continental lithosphere collide resulting in fold-thrust mountain belts. Earthquakes occur due to the thrust faulting and range in depth from shallow to about 200 km. Examples - Along the Himalayan Belt into China, along the Northern edge of the Mediterranean Sea through Black Sea and Caspian Sea into Iraq and Iran.

2.5.5 Intraplate Earthquakes

These are earthquakes that occur in the stable portions of continents that are not near plate boundaries. Many of them occur as a result of re-activation of ancient faults, although the causes of some Intraplate earthquakes are not well understood. Examples - New Madrid Region, Central U.S., Charleston South Carolina, Along St. Lawrence River - U.S. - Canada Border.

2.6 Measurement of Earthquake

2.6.1 Earthquake Magnitude and Intensity

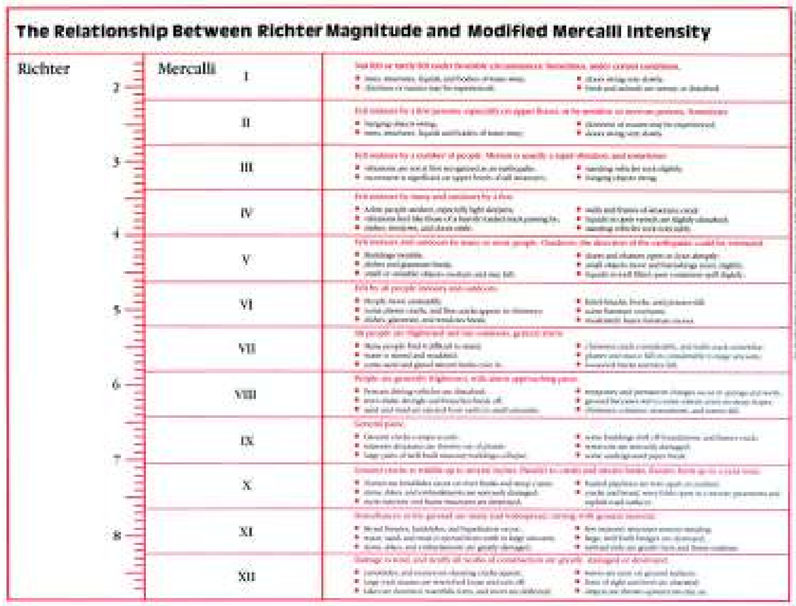
Earthquake magnitude is a measure of the size of the earthquake reflecting the elastic energy released by the earthquake. It is referred by a certain real number on the Richter scale (*e.g.,* magnitude 6.5 earthquake). On the other hand, *earthquake intensity* indicates the extent of shaking experienced at a given location due to a particular earthquake. It's referred to by a Roman numeral (*e.g.,* VIII on MSK scale). Intensity of shaking at a location depends not only on the magnitude of the earthquake, but also on the distance of the site from the earthquake source and the geology / geography of the area.

The concept of earthquake magnitude was developed by Richter and hence, the term "Richter scale". The value of magnitude is obtained on the basis of recordings of earthquake ground motion on seismographs. In practice, there are several different definitions of magnitude; each could give a slightly different value of the magnitude. Hence, magnitude is not a very precise number. Earthquake magnitude is measured on a log scale, and a small difference in earthquake recording on the instruments leads to a much smaller error in the magnitude.

There are no upper or lower bounds on earthquake magnitude. In fact, magnitude of a very small earthquake can be a negative number also. Usually, earthquakes of magnitude greater than 5.0 cause strong enough ground motion to be potentially damaging to structures. Earthquakes of magnitude greater than 8.0 are often termed as *great earthquakes.*

Intensity indicates the violence of shaking or the extent of damage at a given location due to a particular earthquake. Thus, intensity caused by a given earthquake will be different at different places. Prior to the development of ground motion recording instruments, earthquakes were studied by recording the description of shaking intensity. This lead to the development of intensity scales which describe the effects of earthquake motion in qualitative terms.

The most commonly used intensity scales are: *Modified Mercalli (MM) Intensity Scale* and the *Medvedev-Sponhener-Karnik (MSK) Intensity Scale*. Both these scales are quite similar except that the MSK scale is more specific in its description of the earthquake effects. The five seismic zones I, II, III, IV and V in the Indian seismic code (IS:1893-1984) correspond to areas that have potential for shaking intensity on the MMI scale of V or less, VI, VII, VIII, and IX or more, respectively.



Source – Missouri Department of Natural Resources (Division of Geology and land Survey)

Figure 2-8. Relationship between Richter Magnitude and MMI

2.7 Effect of Earthquake on Buildings

The primary effect of an earthquake is shaking of a building or infrastructure. During an earthquake, a building shakes in all possible directions. The shaking loosens the joints of different components of the building that leads to subsequent damage or collapse. The base of the building moves with the ground but the roof tends to stay in its original position. Since the walls and columns are connected to the roof, it tends to bring down the roof along with it. Also when the ground moves, the building is thrown backwards, and the roof experiences a force, called *inertia force.* If the roof has a mass *M* and experiences an acceleration *a*, then from Newton's Second Law of Motion, the inertia force *F1* is mass *M* times acceleration *a*, and its direction is opposite to that of the acceleration. Clearly, more mass means higher inertia force. Therefore, lighter buildings sustain the earthquake shaking better.

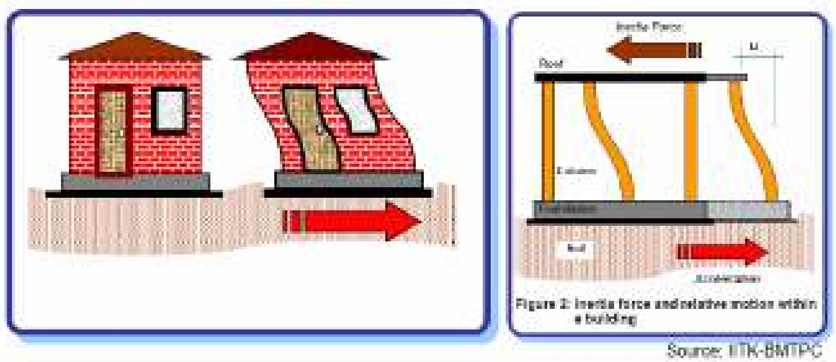


Figure 2-9. Inertia Force and Relative Motion of Building due to Ground Motion

The inertia force experienced by the roof is transferred to the ground via the columns, causing forces in columns. During earthquake shaking, the columns undergo relative movement between their ends. Though, the columns tend to come back to the straight vertical position, i.e., columns resist deformations. In the straight vertical position, the columns carry no horizontal earthquake force through them. But, when forced to bend, they develop internal forces. The larger is the relative horizontal displacement, the larger is the internal force in columns.

2.7.1 Effect on Masonry Structures

Masonry buildings are brittle structures and one of the most vulnerable of the entire building stock under strong earthquake shaking. The huge number of human fatalities in such constructions during the past earthquakes in India corroborates this. Thus it is important to improve the seismic behavior of masonry buildings.

The ground shakes both in vertical and horizontal directions during earthquakes. These forces travel through the roof and walls to the foundation of the building. 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. 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.

2.7.2 Effect on reinforced concrete structures

Reinforced concrete (RCC) consists of two primary materials, namely, concrete and reinforcing steel bars. A typical concrete building is made of horizontal components and vertical components, and supported by foundations that rest on ground. The 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. These forces travel downwards – through slab and beam to columns and walls, and then to the foundations from where they are dispersed to the ground.

In RC buildings the vertical spaces between columns and floors are filled – in with masonry walls to demarcate a floor area into functional spaces (rooms). Normally, these masonry walls or infill walls are not connected to surrounding RC columns and beams. 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.

2.8 Building Type Classification

Seismic resistant capability of a building is closely related to its structural type. For the purpose of earthquake risk assessment of buildings, it is important to study the relation between damage of building and earthquake strength. So a classification of seismic resistant capabilities of buildings must be made in accordance with their structures. Primary seismic risks to buildings are evaluated in terms of two basic criteria:

2.8.1 Based on Construction

On the basis of construction, buildings are classified into two types,

Non-engineered building constructions are those, which are spontaneously and informally constructed in various countries in the traditional manner without any or little intervention by qualified architects and engineers in their design. Such buildings involve fields stone, fired brick, concrete block, adobe or rammed earth, wood or a combination of these traditional locally available materials in their construction. Cement and lime are sometimes used for the mortar.

The engineered construction includes reinforced concrete buildings and structures used for various purposes, which are normally designed, by architects and engineers working together.

2.8.2 Based on roof and wall Materials

On the basis of roof and wall materials, buildings are classified into 4 categories;

Category A
A1. Mud wall – All roofs sloping
A2. Unburnt brick – (i) Sloping Roof, (ii) Flat Roof
A3. Stone wall – (i) Sloping Roof, (ii) Flat Roof

Category B
B. Burnt Brick wall – (i) Sloping Roof, (ii) Flat Roof

Category C
C1. Concrete wall – (i) Sloping Roof, (ii) Flat Roof
C2. Wood walls – All roofs
C3. Ekra walls – All roofs

Category X
X1. GI and Other Metal Sheets – All roofs
X2. Bamboo, Thatch, Grass, Leaves – All roofs

In this respect, it is much more essential to discuss the general behavior of certain building types:

Timber nearly always resists earthquakes quite well. Timber is a relatively ductile material. That is, it can be stretched, bent, and hammered, without loosing much of its strength. This material will also damp the vibrations fairly well. Damping is important in reducing the resonance and overall strain placed upon the building parts.

Steel is very ductile material used commonly in building. E.g., the Transamerica Pyramid in San Francisco, built to withstand earthquakes, swayed more than 1 foot but was not damaged in the 1989 Loma Prieta California earthquake. This is partially due to its steel construction.

Reinforced concrete achieves ductility through careful limits on steel in tension and concrete in compression. Non-reinforced concrete can e easily sheared in responding to ground movement and is a serious hazard when supporting heavy loads. Reinforced concrete construction is rational because it matches concrete, which resists compression with steel, which resists tension. This construction suits free shape design.

Masonry is a very diverse building material. Reinforced masonry behaves similar to reinforced concrete. The boundary between mortar and the masonry unit adds additional failure potential. Non-reinforced masonry possesses little ductility and is not expected to behave elastically as you want material to behave in an earthquake. People have traditionally built their homes with natural materials found nearby. The vulnerability of these buildings is greater, because these materials resist compression but do not resist tension.

2.9 Importance of Architectural Features

The behavior of a building during earthquakes depends critically on its overall shape, size and geometry, in addition to how the earthquake forces are carried to the ground. Hence, at the planning stage itself, architects and structural engineers must work together to ensure that the unfavorable features are avoided and a good building configuration is chosen. The importance of the configuration of a building was aptly summarized by Late Henry Degenkolb, a noted Earthquake Engineer of USA, as: *"If we have a poor configuration to start with, all the engineer can do is to provide a band-aid - improve a basically poor solution as best as he can. Conversely, if we start-off with a good configuration and reasonable framing system, even a poor engineer cannot harm its ultimate performance too much."*

2.10 Architectural Features

A desire to create an aesthetic and functionally efficient structure drives architects to conceive wonderful and imaginative structures. Sometimes the *shape* of the building catches the eye of the visitor, sometimes the *structural system* appeals, and in other occasions *both shape and structural system* work together to make the structure a marvel. However, each of these choices of shapes and structure has significant bearing on the performance of the building during strong earthquakes. The wide range of structural damages observed during past earthquakes across the world is very educative in identifying structural configurations that are desirable versus those which must be avoided.

2.10.1 Size of Buildings

In tall buildings with large height-to-base size ratio (Figure 2-10a), the horizontal movement of the floors during ground shaking is large. In short but very long buildings (Figure 2-10b), the damaging effects during earthquake shaking are many. And, in buildings with large plan area like warehouses (Figure 2-10c), the horizontal seismic forces can be excessive to be carried by columns and walls.

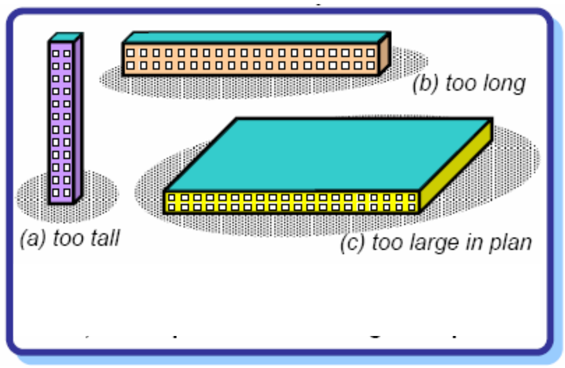


Figure 2-10. Buildings with one of their overall sizes much larger or much smaller than the other two do not perform well during earthquakes.

2.10.2 Horizontal Layout of Buildings

In general, buildings with simple geometry in plan (Figure 2-11a) have performed well during strong earthquakes. Buildings with re-entrant corners, like those U, V, H and + shaped in plan (Figure 2-11b), have sustained significant damage. Many times, the bad effects of these interior corners in the plan of buildings are avoided by making the buildings in two parts. For example, an L-shaped plan can be broken up into two rectangular plan shapes using a separation joint at the junction (Figure 2-11c). Often, the plan is simple, but the columns/walls are not equally distributed in plan. Buildings with such features tend to twist during earthquake shaking.

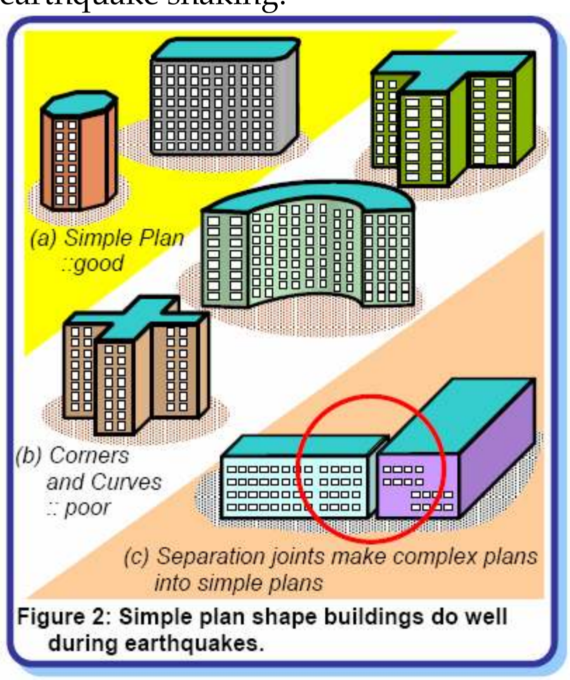


Figure 2-11. Simple plan shape buildings do well during earthquakes

2.10.3 Vertical Layout of Buildings

The earthquake forces developed at different floor levels in a building need to be brought down along the height to the ground by the shortest path; any deviation or discontinuity in this load transfer path results in poor performance of the building. Buildings with vertical setbacks (like the hotel buildings with a few storeys wider than the rest) cause a sudden jump in earthquake forces at the level of discontinuity (Figure 2-12a). Buildings that have fewer columns or walls in particular storeys or with unusually tall storeys (Figure 2-12b), tend to damage or collapse which is initiated in that storeys. Many buildings with an open ground storeys intended for parking collapsed or were severely damaged in Gujarat during the 2001 Bhuj earthquake. Buildings on slope ground have unequal height columns along the slope, which causes ill effects like twisting and damage in shorter columns (Figure 2-12c). Buildings with columns that hang or float on beams at intermediate storeys and do not go all the way to the foundation have discontinuities in the load transfer path (Figure 2-12d). Some buildings have reinforced concrete walls to carry the earthquake loads to the foundation. Buildings, in which these walls do not go all the way to the ground but stop at an upper level, are liable to get severely damaged during earthquakes.

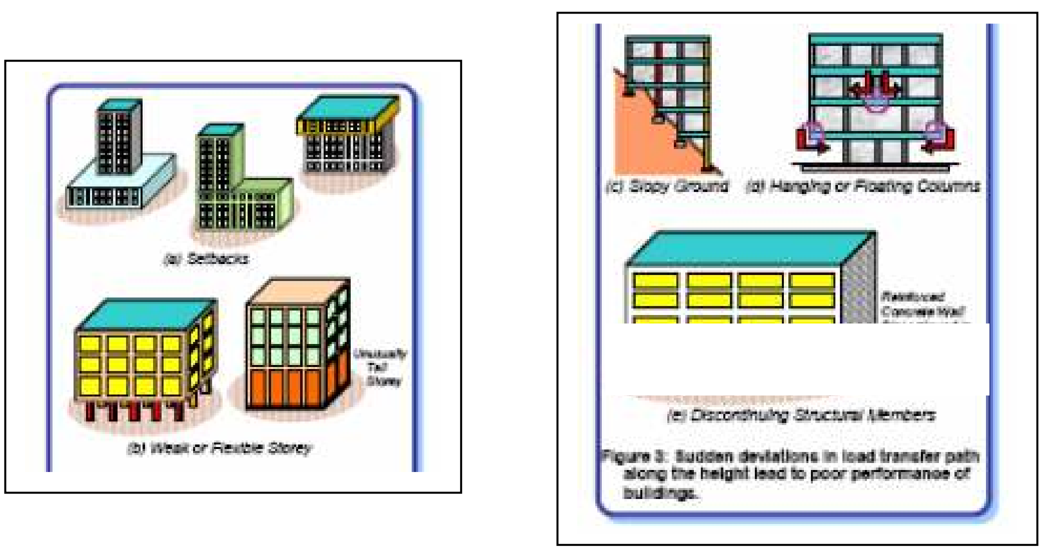


Figure 2-12. Sudden deviations in load transfer path along the height lead to poor performance of buildings

2.10.4 Adjacency of Buildings

When two buildings are too close to each other, they may pound on each other during strong shaking. With increase in building height, this collision can be a greater problem. When building heights do not match (Figure 2-13), the roof of the shorter building may pound at the mid-height of the column of the taller one; this can be very dangerous.

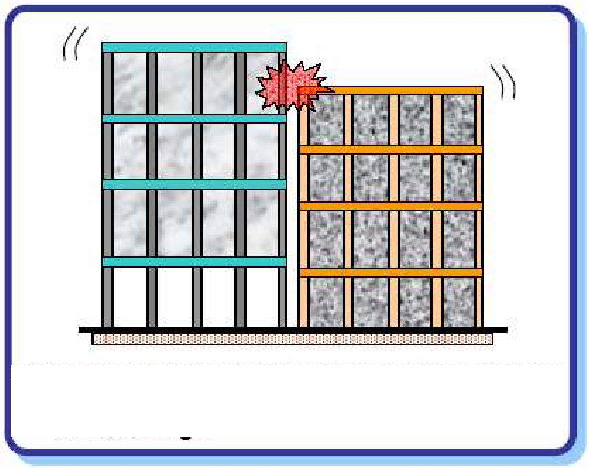


Figure 2-13. Pounding can occur between adjoining buildings due to horizontal vibrations of the two buildings.

2.11 Hazard and Disaster

Hazard is a "inherent danger associated with a potential problem" (Randolph, 2004). The potential problems are,

Weather related – flooding, storm water, rainfall, snowfall, hurricane and tornado wind damage, drought and excessive heat, and lightening.

Geologic – landslides and avalanches, erosion, earthquakes, and volcanic activity.

Ecological – wildfire and disease-carrying wildlife.

Hazards vary from regions to regions as well as specific areas within the region. International Union for Conservation of Nature and Natural Resources (IUCN) defined a natural hazard disaster as "major disruptions of livelihoods and economic processes as a result of extreme weather related or geological hazards combined with vulnerable human systems"

Cambridge Architectural Research Limited (DMTP, 1994) defined Natural hazards as the probability of the occurrence, within a specified period of time and a given area, of a particular, potentially damaging phenomenon of a given severity or intensity. A hazard becomes a disaster when it turns into injuries, loss of life and damage to the infrastructures and properties. Ground shaking, ground rupture, landslides, liquefaction tsunamis are the main earthquake induced hazards, which may cause series of secondary hazards like fire, flood, water pollution, etc.

Davidson (1997) defined earthquake disaster as a function of 'not only the physical impact of earthquake but also the response capacity of the affected city, and the perceived relevance of the physical impact to the city and the world affairs." She argued that the context of the damage would determine the degree of disaster situation and its effects.

Thus, from these definitions it can be concluded that hazard is a potential harmful phenomenon that has certain likelihood of occurrence in an area within a specific time period. Hazard becomes disaster when its damaging effect exceeds certain threshold (though the threshold boundary is fuzzy).

2.12 Vulnerability

Vulnerability to natural hazards conveys broad meaning from different disciplinary perspective. Initially, it was used in the field of engineering to describe the strength of constructions to resist physical forces exerted by ground motion, wind and water. (ISDR, 2002). Later the concept of vulnerability has been used in the field of sociology, economics, hazard studies and others. This study takes the definition from the field of natural hazard studies.

Launching the International Decade for Natural Disaster Reduction (1990 – 2000), united Nations Disaster Relief Coordinator (UNDRO, 1991) defined vulnerability as ' the degree of loss that a given elements at risk or set of such elements resulting from the occurrence of a natural phenomenon of a given magnitude and expressed on a scale from 0 (no damage) to 1 (total loss).

Cambridge Architectural Research Limited (DMTP, 1994) defines vulnerability as the degree of loss to a given element at risk resulting from a given hazard at a given severity level and is usually expressed as a percentage loss or as a value ranging 0 to 1. People or buildings or other elements which would be effected by the hazard, if it occurred, are termed as the elements at risk.

Randolph (2004) defined vulnerability as "the unprotected nature of the exposure". It describes the ease with which the exposed can be harmed in the absence of remedial measures. The exposed can be any of physical infrastructure, people and their livelihood means, economy, and socio-political system. Vulnerability can be reduced by engineering design (e.g., flood proofing, earthquake resistant design, heating and air conditioning systems to temper extreme heat and cold).

In line wit these concepts, structural vulnerability of buildings due to earthquake can be defined as probability of physical loss that buildings would face when a particular level of shaking occurs. It depends on aggregate performance of its components as well as with the characteristics of expected hazard, characteristics of the ground where it stands and its environment such as other buildings.

2.13 Risk

Risk is the probable degree of injury and damage likely to occur from exposure of people and property to hazard over a specific time period. Risk is where a hazard, exposure and vulnerability overlap (Randolph, 2004). The word risk refers to the expected losses from a given hazard and is the product of hazard and vulnerability. The International Strategy for Disaster Reduction (ISDR, 2002) formulates risk as;

Risk = Hazard*Vulnerability/Capacity

To remove this combination of negative (hazard and vulnerability) and positive (capacity) factors Villagran (2004) proposed to replace capacity with its opposite, deficiency in preparedness, and presented the equation as;

Risk = Hazard*Vulnerability*deficiency in preparedness

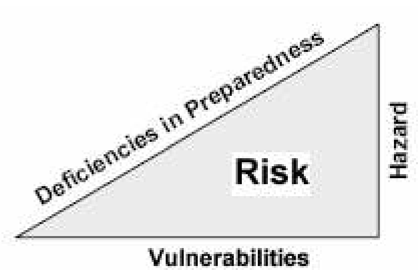


Figure 2-14. The Risk Triangle adopted from Villagran (2004)

The deficiency in preparedness includes conditions, which inhabit the population, the respective authorities, and disaster-response agencies from responding efficiency to minimize loss during the disaster event. This equation can be visualized as a triangle whose sides are the equation components and its area represents the risk.

For calculating building vulnerability due to earthquake, the above equation can be written as;

Risk = (Earthquake intensity X Building Vulnerability)

Risk = (Earthquake Intensity X Site Vulnerability X Building Quality)

Thus for the estimation of buildings damage by probable future earthquake events, all the three factors mentioned above should be studied.

Risk analysis involves combining the assessment of relative hazard, the exposure, and vulnerability as well as analyzing the probability of occurrence. This statistical assessment relies on inventory, historical and scientific data (Randolph, 2004).

Blikie et al. (1994) highlighted the rapidly increasing risk in urban areas in developing countries. These areas usually do not have adequate organization, prevention and evacuation systems and/or disaster preparedness plans in place. On the other hand, the developed countries have devised various ways of protecting themselves from the consequences of disasters by anticipating their risks through prevention and planning measures. Few such measures have been taken in the developing countries, however where a large proportion of the population lives in precarious conditions (ECLAC, 2003).

Chapter
3

3. Study Area

This chapter enumerates on the details of the study area, and a broad framework of the demographics and geographical attributes of the area.

Dehradun, a city situated in the newly formed state of Uttaranchal. Dehradun is one of the oldest cities in India its reference is even fiven in the written that dates back to 250 BC even the great king Ashoka's inscriptions can be found outside the city. There are 14 edicts carved on a rock and the site where Raja Shilvarma of the Vrisheri dynasty sacrificed three horses. Large bricks with writing on them are laid out in the shape of a huge bird with a fire altar in the middle.

In the ancient Vedic times, the Garhwal Mandal, of which Dehradun is a part, was known as the Kedar Khand. Legend has it that Guru Dronacharaya, a Brahmin teacher of warfare, found Dehradun a place that was fit for meditation & worship and therefore, the valley of Doon was christened Drona Ashram, which means "The Abode of Drona". Perhaps that is why Indian army trains its finest cadets in the Indian Millitary Academy that is situated in this part of the state.

Dehradun has always been famous for various educational institutes that are present in the city. Its close proximity from the bustling city of Delhi and another tourist attraction Mussoorie adds to the attraction of the city. Its mild climate and the list of endless places to visit in the city make it an important tourist attraction.

3.1 Geographical Location

The city of Dehradun is situated in the south central part of Dehradun district. Dehradun city lies at 30° 19′N and 78° 20′E. The area under the administrative control of the Dehradun municipal board is 38.04 sq. km. The Dehradun municipal board was divided into 34 wards according to the 1991Census. Two intermittent streams viz. Rispana River and Bindal River, on the east and west respectively marks the physical limits of Dehradun municipality. The city is located at an altitude of 640 m above MSL. The lowest altitude is 600 m in the southern part and the highest altitude is 1000 m in the northern part. The site where the city is located slopes gently from north to south and southwest and is heavily dissected by a number of seasonal streams and 'nallas'. The drainage of the city is borne by the rivers Bindal and Rispana.

3.2 Climate

The average temperature of the city is 36 + 6o C and the minimum is 5 + 2o C. In summer, the maximum temperature is 36 + 6o C, and the minimum temperature is 16 + 7o whereas in winter it varies from 23 + 4o C and 5 + 2o C respectively. In summer the heat is often so intense that the temperature on a particular day may rise to over 42o C. January is the coldest month and the minimum temperature occasionally falls down to a degree below the freezing point. Inversion of temperature is a conspicuous phenomenon, due to the location of the city in the valley. The average annual rainfall of Dehradun is 2183.5 mm. About 87 percent of the rainfall is through monsoons and is received through the months from June to September, July and August being the heaviest. The relative humidity is the highest during the monsoons normally exceeding 70 percent on an average. The driest part of the year is usually during the summer season, when the relative humidity becomes less than 45 percent.

3.3 Soil Characteristics

The type of soil, i.e. structure, texture, organic matter content, its infiltration capacity and permeability, greatly affects the soil loss and run-off. Fine soils are more susceptible to erosion than coarse soils, since rainwater enters in and passes through a dense clay much more slowly than through a porous sand or gravelly soil. In India, it has been observed that deep lateritic soils at Ootacamund and red soils at Deochanda have the lowest rate of run-off; the alluvial soils at Vasad and Dehra Dun have a very high rate of run-off; the black soils have an intermediate rate of run-off, but still the rate of run-off is high. Lateritic clays are less erodiable. The soil left in loose and pulverized condition is particularly liable to erosion through sheet-wash and gullying.

3.4 Ground Cover and Land Use

When rain falls on a surface covered by a thick mantle of plants, its velocity and erosive power are reduced and most of the water either quickly percolates through the soil or moves over the surface with non-erosive velocity. Areas not protected with thick cover of plants are unable to absorb water effectively, because the dashing rains shatter the soil surface, the fine soil particles go into suspension and the thick mixture of water and soil quickly fills and closes the tiny interstices in the soil, reducing infiltration and consequently increasing run-off and soil loss.

3.5 Settlement Structure and Urban Form

The settlement structure of Dehradun depicts morphological expansion over a colonial structure. The Eastern Rajpur canal was the most important feature in Dehradun during the British period that had served the needs of water for drinking and agricultural purposes. The central part consists of the old city, i.e. the colonial vestiges, and 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 southern part of the city is designated as an industrial area.

3.6 Demographic Aspects

As a part of the past heritage, concentration of national and regional level institutions, and economic activities, availability of infrastructure, and the emergence of Dehradun as the state capital on November 2000, would further invite the influx of population from the rest of the valley as well as from outside. This would further increase the growth rate in addition to the natural increase of population within the city itself. Favorable climate, good regional linkages by rail and road, and feasibility of spatial expansion of Dehradun would be therefore instrumental for further migration. However whether the city would support this population expansion on a sustainable basis also calls for a detailed insight into the socio-economic characteristics of population that in turn decides the quality of population as well as certain aspects of urban planning and urban environment.

3.7 Socio-Economic Functions of Dehradun City

Cities come into existence due to the functions they perform as central places. A harmonious integration of functions and activities can lead to a healthy and orderly development of the city. The major town functions of Dehradun can be grouped under:

Administrative: Dehradun is the capital of the newly formed state of Uttaranchal.

Educational and Institutional: The city besides being the seat for prestigious educational institutions, and other technical institutes, are also famous for national level institutes as already stated.

Commercial: Dehradun is the largest service center within the hilly region of Uttaranchal. It meets the trade and commerce requirements of its region. With the expansion of national level institutes and offices, and the expansion of the cantonment area, the commercial activity had gained momentum.

Industrial: Establishment of industries based mainly on limestone and forests have attracted ancillary industrial units and other industries. Development of industries is likely to play a vital role in building a sound economic base of the city.

Tourism: Dehradun is endowed with immense potentialities for tourism industry besides being gateway to Mussoorie, the Queen of Hill Stations.. There are a number of tourist places and recreation spots within a short distance of the city that can be developed adequately.

Defence: Dehradun is the headquarters of Indian Military Academy. A number of other defence establishments also are in Dehradun. The defence function has played a vital role in shaping the development and economy of the town.

3.8 Study Area

In order to study the vulnerability assessment of buildings and population, the Dalanwala ward has been selected. An in-depth and detailed study of each and every building and its population has been done in this area. The main reason of selection of this ward has been the rapid level of urbanization in this area over the last 5 years and also the immense amount of illegal and unconsolidated construction that has taken place in this area. The part of Dalanwala that has been selected is situated on Haridwar road. It extends from 78° 56′ E, 30°35′N to 78° 38′ E, 30° 01′N. The study area falls within two wards, number 10 and 12 and called Dalanwala South and Dharampur. This area is characterized by an unplanned urban growth. It is surrounded by Ajab Pur Kalan ward in the south, Race Course ward in the southwest, Race Course North ward in the west, M.K.P. in the north, Dalanwala North ward on the northeast and Rajeev Nagar and Adhoiwala wards on the east of the study area.
(Figure 3-1)

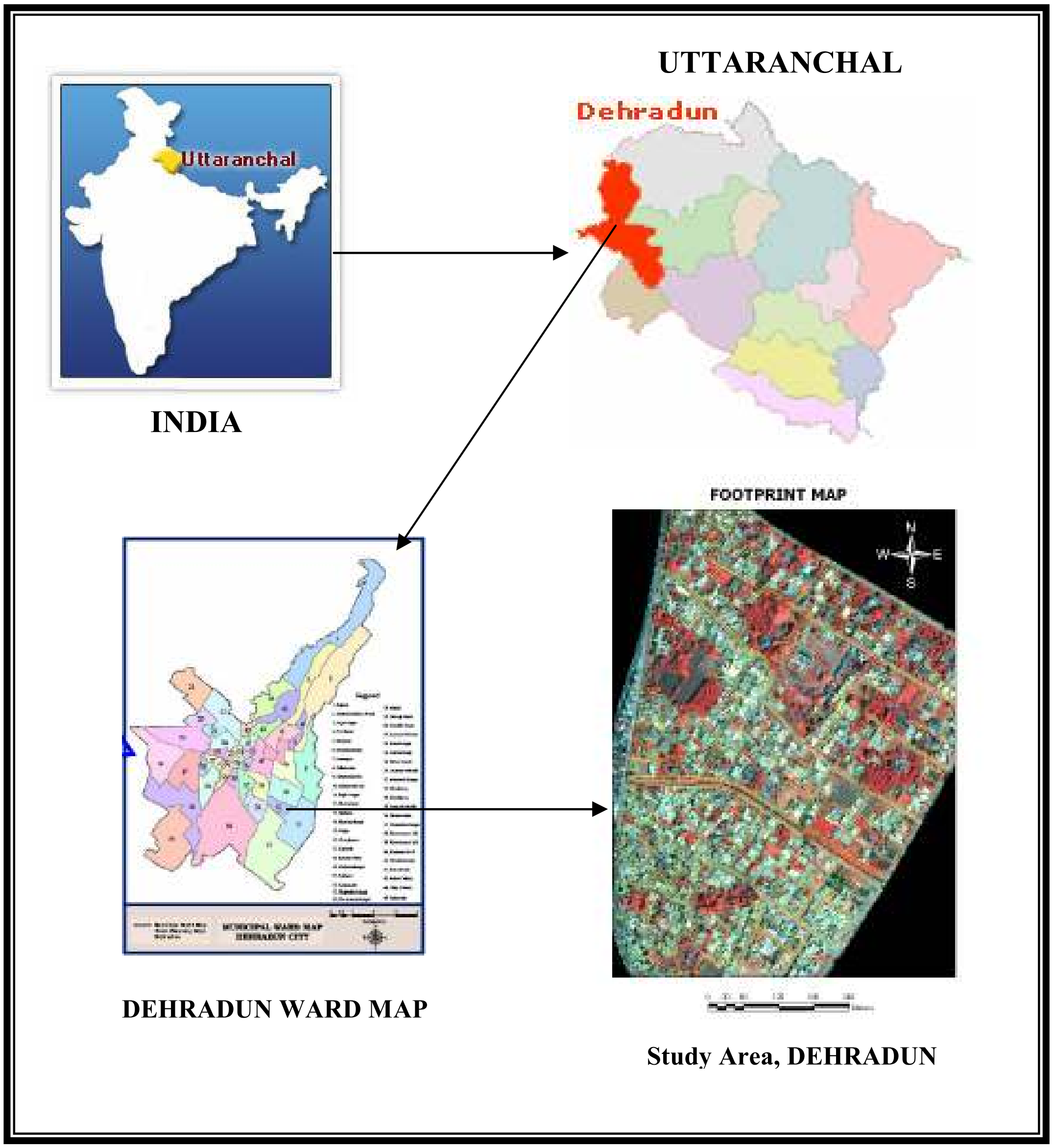


Figure 3-1. Study Area

3.9 Population Characteristics

Dehradun is the largest and capital city of Uttaranchal state. The total population is 1.282,143 persons according to Census of India 2001. The total number of males is 679,583 and females are 602,560. The sex ratio of this area is 887/1000 males.

According to the Census of India 2001, the total population in the wards of Dalanwala South and Dharampur are 9719 persons and 4886 persons, respectively. Out of this, 5210 are males and 4509 are females (Figure 3-2) in Dalanwala South; 3108 are males and 1778 females in Dharampur. The sex ratio is 865/1000 in Dalanwala South and 572/1000 in Dharampur.

The population within the age of 0 to 6 years is 1102 persons and 512 persons, respectively.

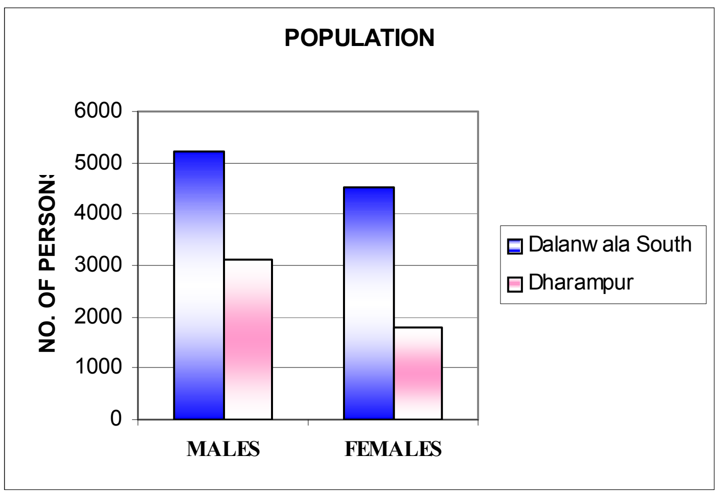


Figure 3-2. Population in the study area

The number of literates in both the wards is 7333 and 3766, respectively. Of these 2587 persons are males and 1179 are females in Dalanwala South. (Figure 3-3)

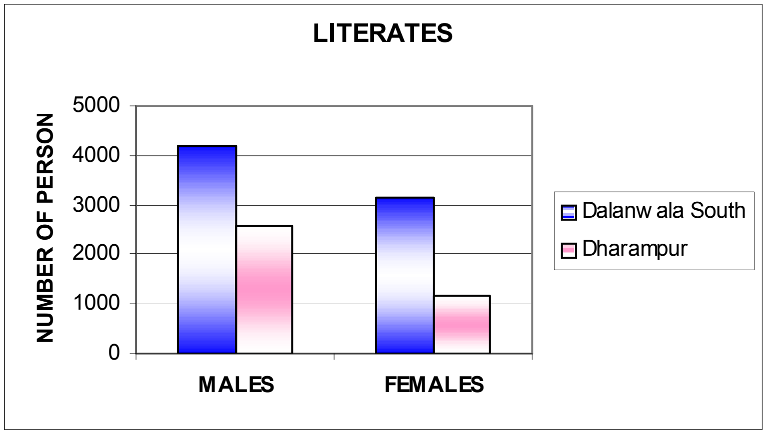


Figure 3-3. Number of literates in the study area

And the number of illiterates is 2386 and 1120, of which 521 are males and 599 are females in Dharampur. (Figure 3-4)

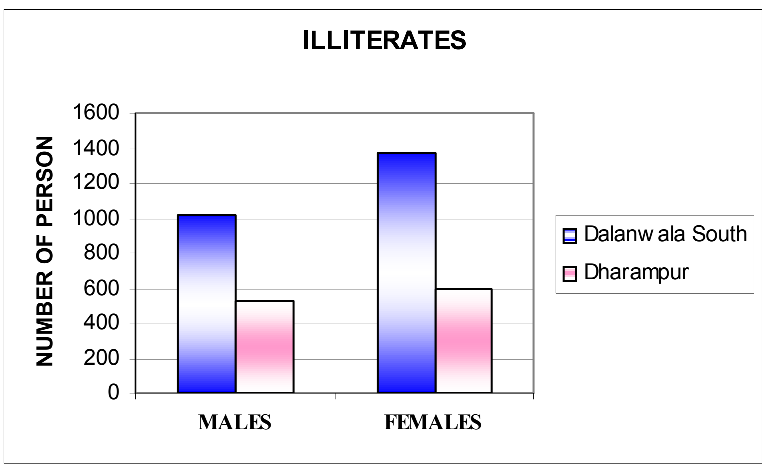


Figure 3-4. Number of illiterates in the study area

Total number of workers in Dalanwala South is 2789, of which 2485 being males and 304 females. In Dharampur, total number of workers is 1050; of which 888 is males and 162 is females. (Figure 3-5)

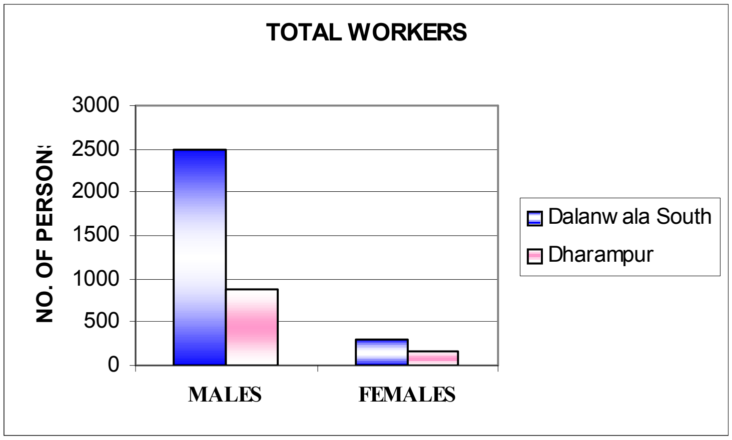


Figure 3-5. Number of workers in the study area

The total number of non-workers in Dalanwala South is 6930; of which 2725 are males and 4205 are females. In Dharampur, the total is 3036; of which 2220 are males and 1616 are females. (Figure 3-6)

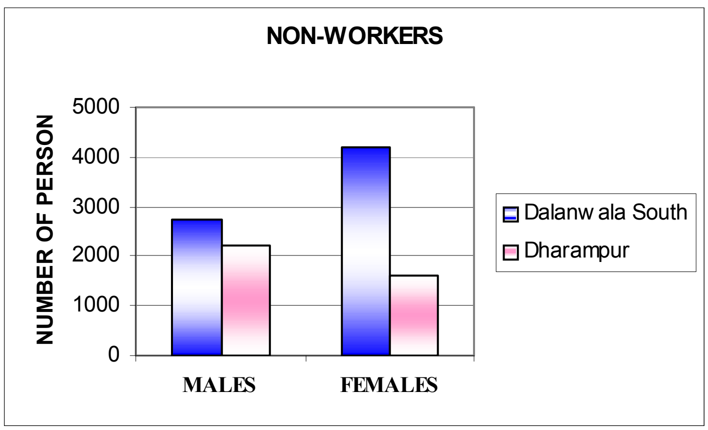


Figure 3-6. Number of non-workers in the study area

3.10 Housing

The quality of urban life is largely affected by the housing areas, which cover large portion of an urban settlement. The main housing areas are Rest Camp, Karanpur, Dalanwala, Govindpur, Rajpur, and newer colonies like Satya Bihar, Rajender Nagar, etc. the gross residential density of the city is 75 persons/hectare. Though in the localities like Jhanda Mohalia, Dandipur, Dhamawala, Balliwala, Kishanpur, etc, most of the housing areas have zigzag narrow roads, which are difficult to widen, and there is also a general lack of open spaces. The relatively new housing areas along Haridwar road, Mussourie road and Chakrata road are more of developed colonies. The number of households are 1901 and 769, with a household size of 5.1 and 6.4, respectively, in both the wards. (Figure 3-7)

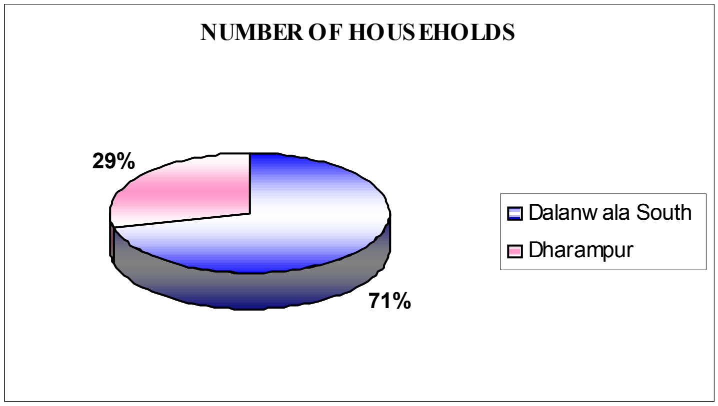


Figure 3-7 Number of households in the study area

Chapter

4

4. Methods and Materials

This chapter deals with the data collection methodology and technique. It also provides details of the data sources and outlines the methodology used to carry out the research work.

4.1 Data Used

The remote sensing data of IKONOS (both MSS (4m) and PAN (1m) data) was used for the study. It was taken for the year 2000 and 2005. It was acquired on April 2000 and 2005 (Table 4-1).

4.2 Specifications of various sensors and data used

Sensor characteristics	IKONOS PAN	IKONOS MS
Ground Resolution	1 meter	4 meter
Spectral bands	0.45 – 0.90 μm	0.45–0.52μm, 0.52–0.60μm 0.63-0.69μm, 0.76-0.90μm
Study Area	Dalanwala, Dehradun, India	Dalanwala, Dehradun, India
Acquiring date	April, 2000, and 2005	

Table 4-1 Specifications of Sensor and Data used

4.3 Ancillary data

Survey of India Topographic Map of 1:50,000 scales cover the entire study area. This map has been used for georeferencing of IKONOS data and identification of major landmarks. Also the SOI guide map of 1:20,000 scales has been used for visual interpretation, identification of roads and selection of training sets during field verification (Table 4-2).

SOI Map no.	Scale	Years of survey	Year of publication
Toposheet 53 J/3	1:50,000	1983-84	1988
Guide Map	1:20,000	1965-68	1982

Table 4-2 Details of maps used

4.4 Other data

A ward boundary map and population data of Dehradun city has been collected from MDDA and Nagar Nigam, Dehradun.
Also, the existing lineament map of Dehradun City has been collected from Geosciences Division, IIRS.
A plan of Dalanwala area in digital form (.dwg) has been acquired from MDDA.

4.5 Hardware and Software Used

Hardware / Instrument –

- Computer
- Scanner
- Printer
- Plotter

Software Used –

- Arc GIS 9
- ERDAS Imagine 9.1
- MS Office

4.6 Methodology

Earthquake risk assessment is made by doing a detailed analysis of hazard intensity and vulnerability of buildings. Seismic risk analysis could give the probability of damage and loss from nearby earthquake. Socio-economic data, housing statistics with vulnerability functions of buildings are required for quantification of risk. The damage to a building due to earthquake depends on a number of factors like method of construction, material type used, building configuration, age of building, number of storeys, size of building, etc. Thus, according to available time and resources, analysis is done taking the main building parameters into consideration (Figure 4-2).

The socio-economic parameters that were used included population during daytime and nighttime, ownership or tenancy, occupation and various assets data that would be damaged, during different earthquake intensity. Urban densification of the area has been studies with the help of satellite images that were taken at different time scale. Therefore, to estimate the level of urban density, vulnerability of buildings and population at risk in the study area, the methodology adopted for this research is given below:

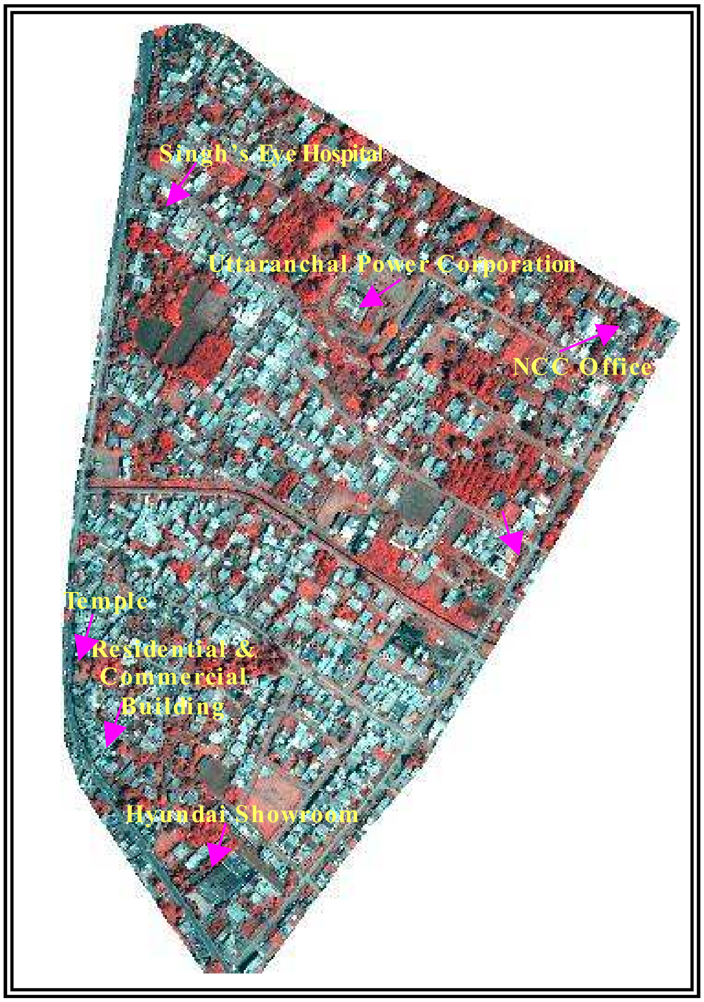


Figure 4-1 Study Area, part of Dalanwala South and Dharampur.

METHODOLOGY

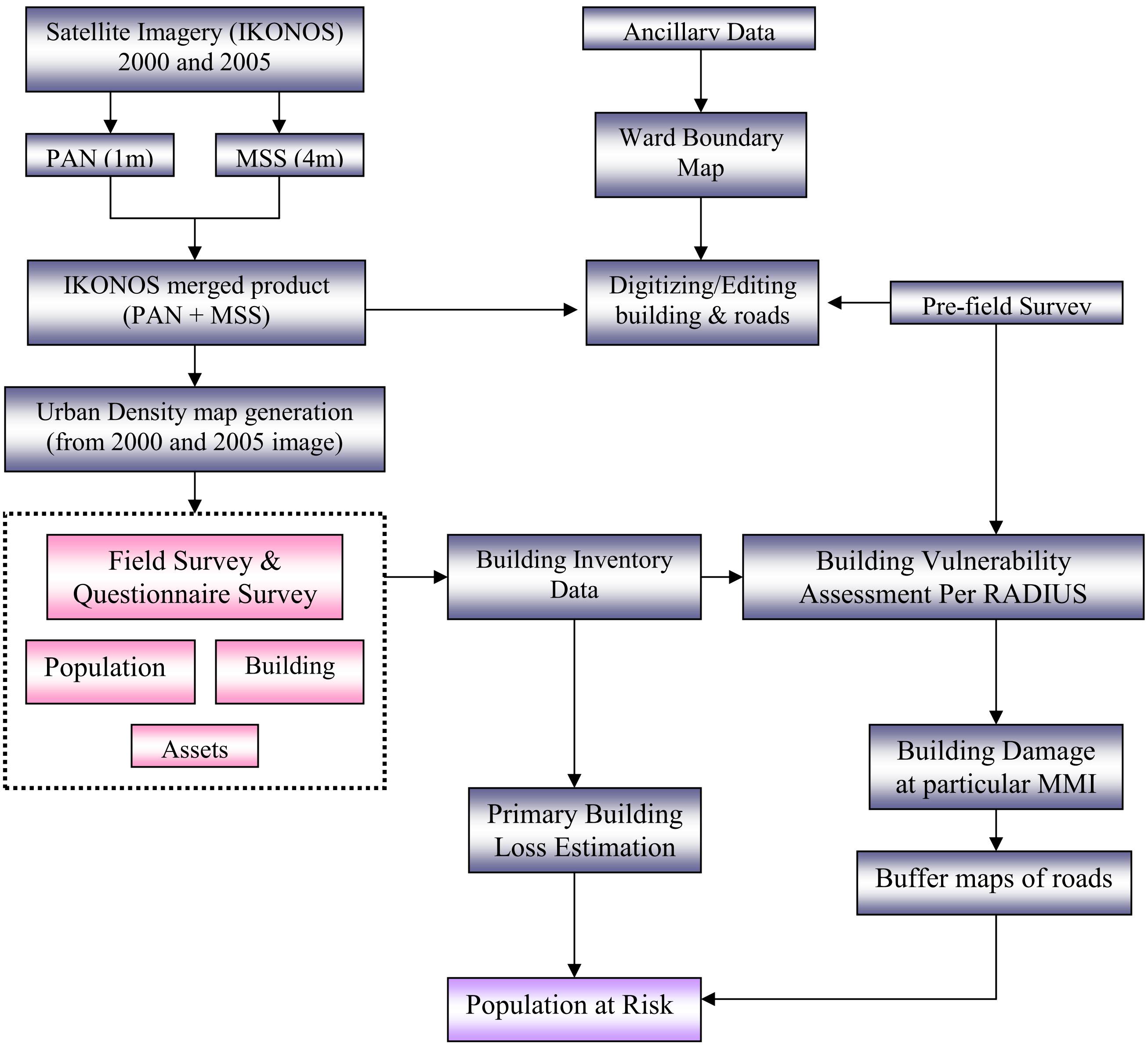
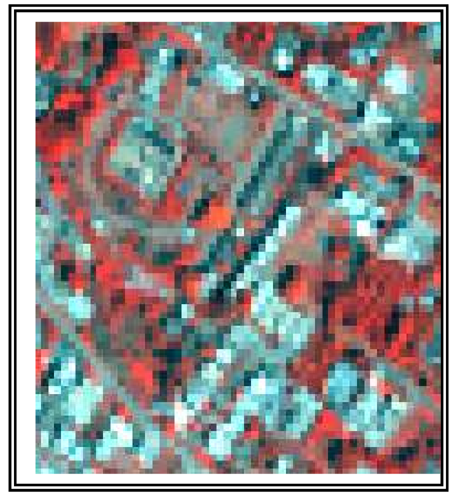


Figure 4-2 Flowchart of Methodology

4.6.1 Merged IKONOS imagery

Firstly, the geocoded IKONOS image was geometrically corrected using the Survey of India topographical map sheet at scale 1:50,000. Well-distributed Ground Control Points (GCP) was selected. Then registration of IKONOS PAN and IKONOS MS image was done, with the help of selected GCP's from both the images. Using various contrast enhancement techniques the final merged image was taken up for visual interpretation. The spectral characteristics of the merged data were thus, much improved and helped to extract urban features in a better way (Figure 4-3).

IKONOS PAN Image (1m)



IKONOS MS Image (4m)

IKONOS Merged Image (1m)

Figure 4-3 IKONOS merged data

4.6.2 Interpretation of Image

Extraction of urban features was difficult due to the presence of mixed built-up areas. Moreover, when imaged with coarse spectral resolution, various urban materials produce almost similar spectral reflections. So it was difficult to separate one specific urban class of information from the other based on spectral characteristics. Thus, the demarcation of each and every building is quite subjective as it depends on an interpreter's ability of discrimination one building from the other. Through visual interpretation techniques using image elements such as tone, texture, shape, size, shadow, pattern, association and location, the building footprint map of the study area was prepared. The details of these elements in identifying building areas are:

a) **Shape:** Shape refers to the general form, configuration or outline of individual objects. Each object has its own shape and its characteristics help in identifying the object. Thus, buildings, roads (primary & secondary) were identified using these characteristics.
b) **Site:** This element of visual interpretation is used to separate tenements verses multi-storied buildings; runways verses roads etc. A thorough understanding of the scale of the imagery and resolving power of the sensors are essential in any site analysis.
c) **Shadow:** Shadows are extremely useful to the interpreters when they are correctly interpreted. Using shadow characteristics one can separate building areas as well as can differentiate between one and more storied buildings when situated closely or they have very narrow gap in between.
d) **Pattern:** It is the spatial arrangement of objects and it is valuable tool for interpretation. Typically an orderly repition of similar tones and textures will produce a distinctive pattern that helps in determining building characteristics.
e) **Tone:** Tone differences are the most important aspect of visual interpretation. Objects of different color have different qualities of light reflectance and appear in varying shade of gray. Without the tone difference, the shape and pattern could not be discerned.
f) **Texture:** Texture is the result of uniform tonal changes caused by objects, which are too small to be clearly distinguished individually. Texture ranges from smooth or fine to coarse depending upon the scale of the image. With the help of this property, buildings having various rooftops and time of construction can be roughly interpreted.

g) **Location and Association:** These are not object characteristics but denote its immediate surrounding. Association is a skill developed by the interpreter, which involves a reasoning process, which uses all the principles of interpretation to relate an object to its surroundings.

The municipal ward boundary map was digitized on screen based on municipal ward map (1:20,000) prepared by the Municipal Corporation of Dehradun. AOI of the study area was created from IKONOS image and then with the help of visual interpretation, the footprint map of the area was made. Buildings and roads were made and each was given unique ID for use during field survey. This base map was then verified during pre-field survey.

4.6.3 Database Generation

Since no individual building data or map was available, ground truthing and field survey was an integral part of this study. Printouts of the footprint map were used along with the related questionnaire during field survey. The parameters used for building inventory, population and assets were selected after a considerable literature survey.

Field survey took up a considerable amount of time as each and every house had to be visited and questions were asked related to population and assets. In this way, individual building layers were generated after editing the existing footprint map and also digitizing the new buildings on the map. Thus, the total numbers of buildings surveyed were 738.

The building inventory data included:

- Building use (residential, commercial, educational, etc.)
- Roof materials
- Building materials
- Number of storeys
- Maintenance
- Age of building
- Building shape
- Proximity

The population data, which was done with the help of questionnaire, included:

- Number of members in the house
- Population during daytime
- Population during nighttime
- Owner or tenant
- Occupation

Other data that was collected included:

- Road width in front of the buildings
- Presence of open spaces around the building
- Road width
- Road material
- Road type
- Assets in the buildings, included:
  - Four wheeler
  - Two wheeler
  - Cycle
  - Television
  - Refrigerator
  - Washing machine
  - Cooler/AC
  - Computer

After acquiring all these data, the database was generated using ArcGIS. Each of these data was assigned to the individual houses and this database in turn was the key for the vulnerability assessment of the buildings.

4.6.4 Urban Densification study

Digitization of buildings, open spaces and roads were done for the year 2000 also from the respective image. And this was later analyzed with the current map of 2005. Density growth was then evaluated and quantified. This was primarily based on visual interpretation and field survey.

4.6.5 Rationale for Damage Assessment

In this research, the damage probability matrix that has been used has been adopted from the RADIUS Handbook. Various building classes have been designated to the individual buildings based on their building attributes like, building type, roof material, building symmetry, maintenance and age of the building. Then these building classes have been related to various intensities (MMI) of earthquake and the damage probability of the buildings has been calculated (Table 4-3).

In the building type attribute, only two types have been used, namely, load bearing and framed structures. These are the two most prevalent structures found in the study area. The roof materials that were mostly seen in the area was either RCC (Reinforced Cement Concrete) or RBC (Reinforced Brick Concrete).

The maintenance of the buildings was good, moderate or poor and the age varied between new buildings to very old ones. The matrix used is shown below:

Building Class	Building Type	Roof Material	Symmetry	Maintenance	Age
A	Load bearing	GI/Other	Any	Low	Any
A1	Any	Any	Any	NA	NA
B	Load bearing	GI	Any	Any	Any
B1	Load bearing	GI-RCC	Symmetrical	Moderate	Old
C1	Load bearing	RBC/RBC-GI	Asymmetrical	Any	Old/Mod
C2	Load bearing	RBC/RBC-RCC	Symmetrical	Any	Old/Mod
C3	Load bearing	RCC/RCC	Any	Any	Old/Mod
D1	Framed	RCC	Symmetrical	Low	Old
D2	Framed	RCC/GI	Asymmetrical	Moderate	Old
D3	Framed	RCC	Any	Any	Mod/New
D4	Framed	RCC	Any	High	New
E	Steel/GI	Steel	Symmetrical	High	Any

MMI	A	A1	B	B1	C1	C2	C3	D1	D2	D3	D4	E
VI	0.10	0.10	0.04	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
VII	0.45	0.45	0.20	0.20	0.10	0.10	0.05	0.03	0.02	0.00	0.00	0.00
VIII	0.60	0.60	0.45	0.45	0.25	0.30	0.18	0.12	0.06	0.03	0.01	0.01
IX	0.80	0.80	0.60	0.60	0.45	0.60	0.40	0.30	0.17	0.12	0.06	0.06
X	1.00	1.00	0.80	0.80	0.65	1.00	0.72	0.55	0.35	0.25	0.17	0.17
XI	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.85	0.60	0.50	0.35	0.35

Table 4-3 Damage Probability Matrix

Using the above damage probability matrix, the vulnerability assessment of all the buildings was calculated. The probability of the damage of buildings have been estimated according to:

Probability > 75% is taken as Total Collapse
Probability of 51% to 75% is taken as Major Structural Failure
Probability of 31% to 50% is taken as Major Damage Failure
Probability of 5% to 30% id taken as Minor Damage
Probability < 5% is taken as Little/No Damage.

The above damage probability matrix has helped to identify the damage that would occur at various intensities of earthquake. Also a query was done to analyze the effect of these buildings on the road, at various intensities. This was primarily done to evaluate the effect of road and what would be the outcome, based on which it can be found whether relief could be sent to all corners of the area in case a severe earthquake hit the area.

Chapter 5

5. Results and Discussions

This chapter deals with analysis of the data and inferences are drawn on each aspect of the study from both primary and secondary sources of information. It establishes the use of information gathered for the risk assessment study and also shows the urban densification scenario. Various query's have been made and shown with the help of maps.

5.1 Urban Densification

Urbanization in India is neither unique nor exclusive but is similar to a worldwide phenomenon. Indian urbanization has proceeded as it has elsewhere in the world as a part and product of economic change. Occupational shift from agriculture to urban-based industry and services is one part of the change. After the capitalization of Dehradun, it has been observed that the population density has increased at a rapid rate. As per the census of 2001 the population of Uttaranchal is 84.80 lakhs. Over the past decade the population has attained a growth rate of 1.9%. The State has 13 districts spread over an area of 53,119 Sq. km.

The first part of this research includes the evaluation of urbanization that has taken place in the study area over a given span of time. (5 years). Urbanization leads to various problems relating to accommodation of the increased population and this in turn leads to unplanned growth of buildings. At times, the authorities are not able to control the rapid growth that takes place. In Dehradun, a similar situation has taken place, where a rapid growth of urban area has lead to unplanned building construction and lessening of road width.

The study area is a part of Dalanwala south and Dharampur ward of Dehradun. IKONOS images of the year 2000 and 2005 have been acquired to detect the density of buildings that has taken place over these five years. It shows a remarkable increase in building construction and also the main roads have thinned down considerably. Illegal encroachment in the form of small shops and commercial areas has also distinctly cropped up in this area. The following map shows the Landuse of the area in the year 2000.

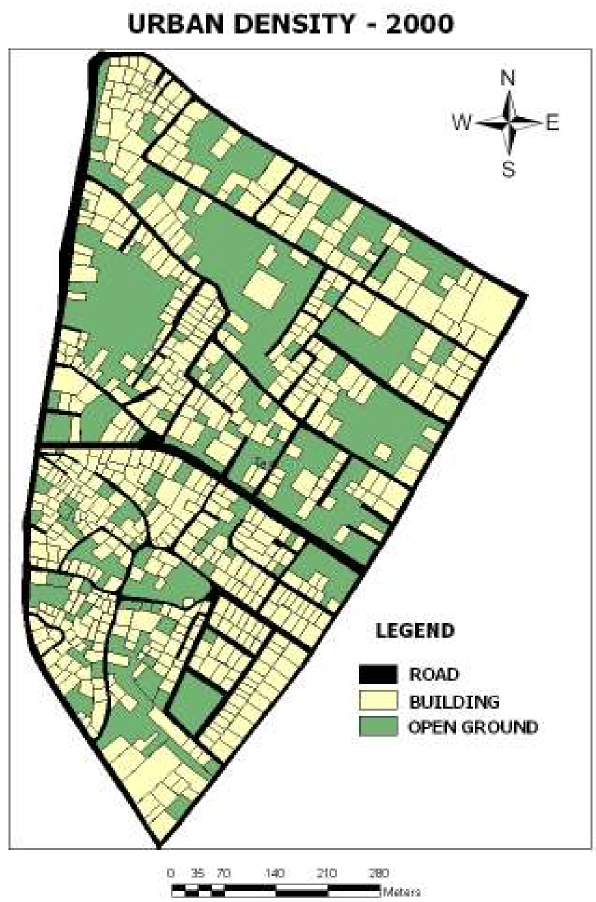


Figure 5-1 Urban Density Map of 2000

The urban density map of the area in the year 2005 (Figure 5-2) shows a marked increase in building construction. In the year 2000, the total number of buildings in the area was 621 (Figure 5-1). This increased to 738 buildings in 2005. A marked increase of 117 buildings has occurred over 5 years. That shows a 23.5 building construction every year. Thus, a 15% increase of buildings occurred in this area, in a year (Figure 5-3).

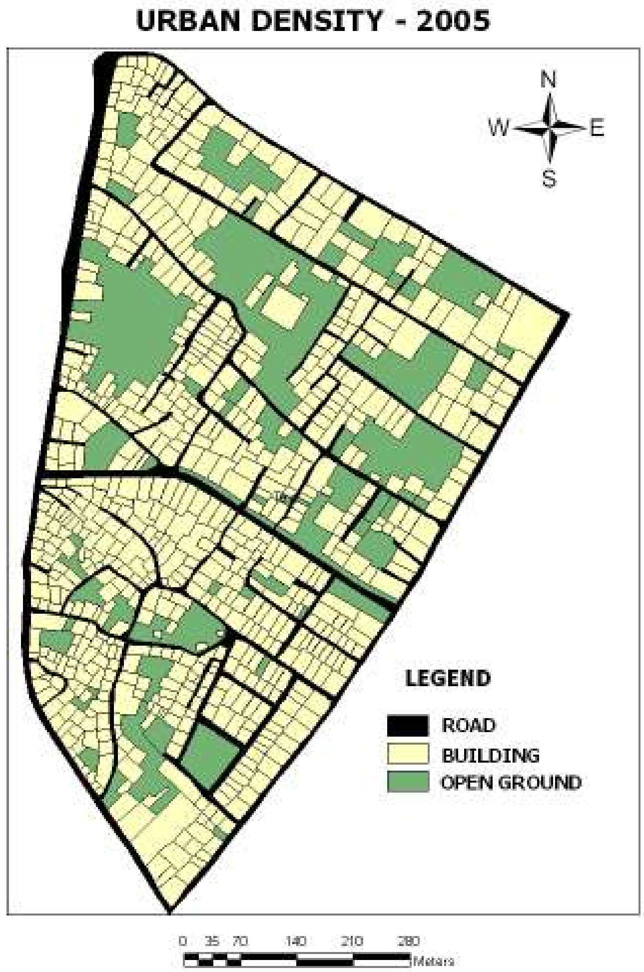


Figure 5-2 Urban Density Map of 2005

This level of urban densification requires a much needed vulnerability assessment study of the area. The growth of population in accordance to building construction leads to various unwanted complexities. The damage that would occur in this area would manifold and thus a detailed damage assessment at different intensity of earthquake is required.

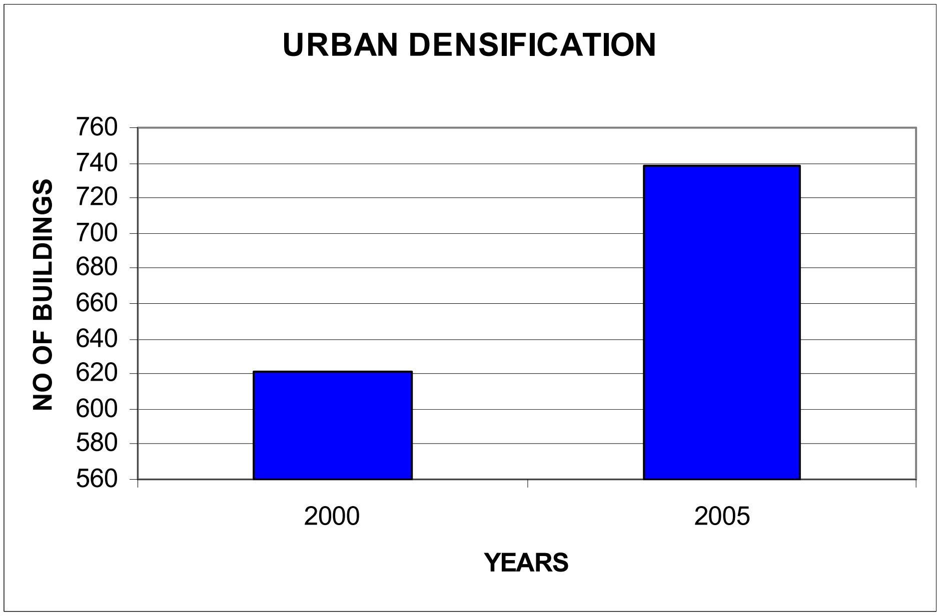


Figure 5-3 Graph showing urban densification

5.2 Landuse

The Landuse of the area shows the presence of residential buildings, utility buildings that included schools, offices, hospitals and some workshops, residential and commercial buildings that have both residential area flanked with shops in the front section of the building and open spaces in the form of playground, open ground without any vegetation and some open spaces which have trees and bushes. The following map (Figure 5-4) shows the Landuse of the area. The residential area covers about 229422 sq meters, residential and commercial areas cover an area of 11642 sq meters, open space covers about 102276 sq meters, roads around the area and within is about 50454 sq meters and utility buildings have taken up about 21803 sq meters. The total area that has been studied is of 415600 sq meters. Thus the residential buildings is about 55% of the total area, residential and commercial area is about 2.8%, open space is about 24.6%, roads is 12.14% and the utility buildings have taken up the rest of the area, 5.2%. (Figure 5-5)

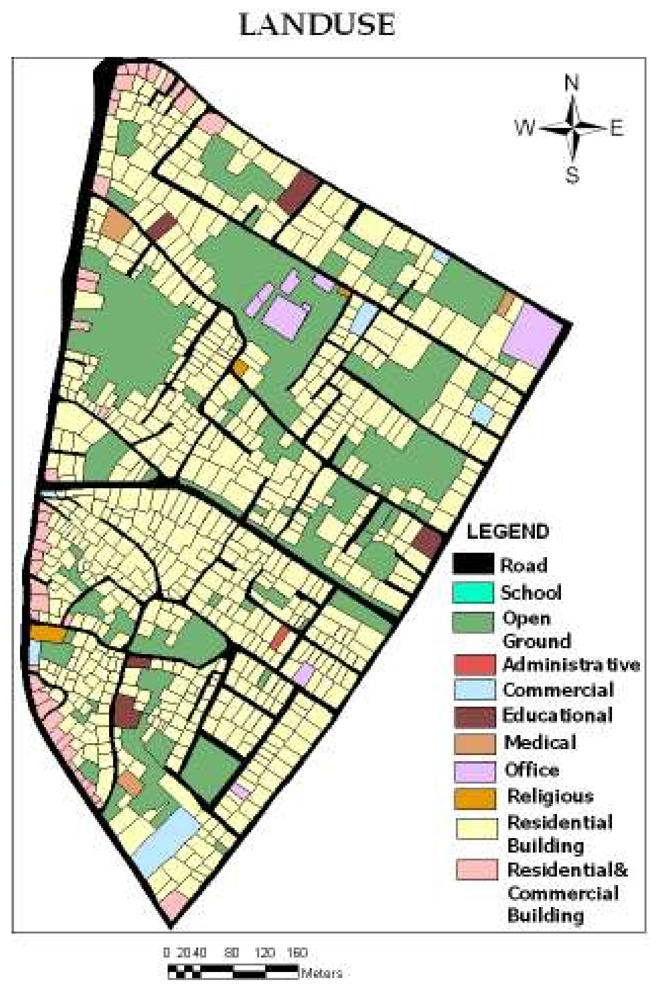


Figure 5-4 Landuse Map

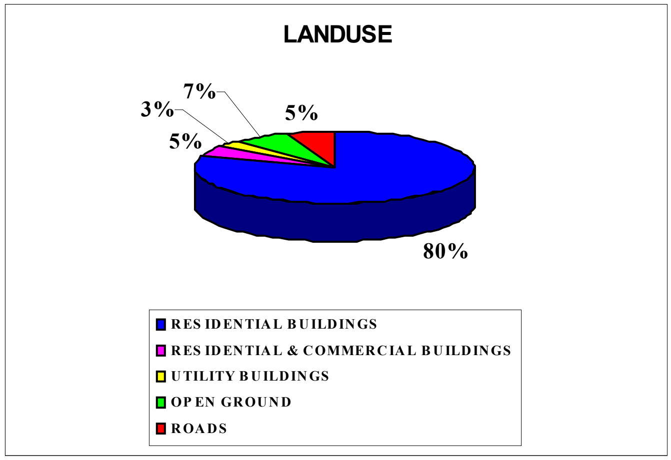


Figure 5-5 Graph showing Landuse distribution

5.3 Building Inventory

The building inventory database has been made from the field survey that was conducted in the study area. The main parameters included building type, roof material, building shape, building age, maintenance, and proximity.

5.3.1 Building Type

The type of building found in the study area was mainly framed structures or load bearing structures. No other types of buildings were found. Framed buildings were 311 and load-bearing structures were 427. A mix of old constructed and modern built structures were found. (Figure 5-6)

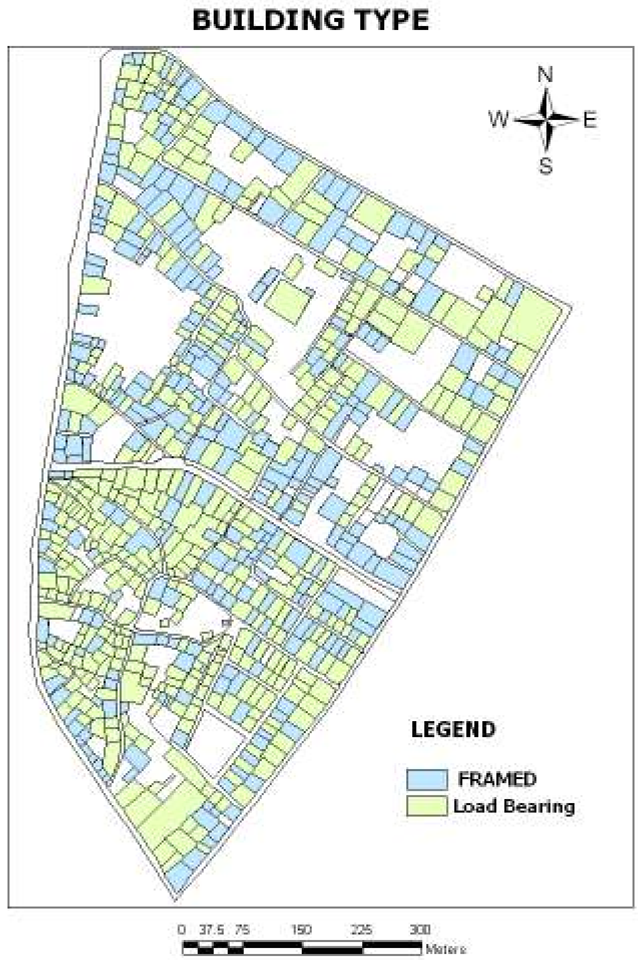


Figure 5-6 Map showing Building Type

5.3.2 Roof Material

The roof materials mostly found in the area were either RCC or RBC made. The number of buildings was 311 and 427 buildings, respectively (Figure 5-7). The striking factor in this is that those buildings, which were load-bearing structures, had RBC roofing and the framed buildings had RCC roofing. This is predominantly because of the fact that prior to a few years the buildings were load-bearing with RBC roofs and the latest ones were constructed with framed structures with RCC roofs. (Figure 5-8)

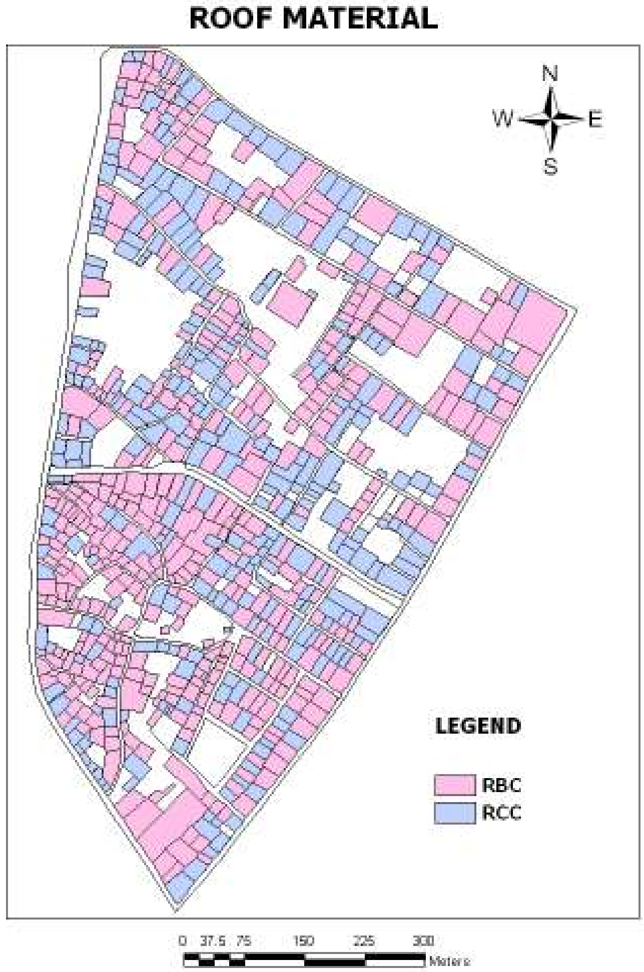


Figure 5-7 Map showing Roof Material

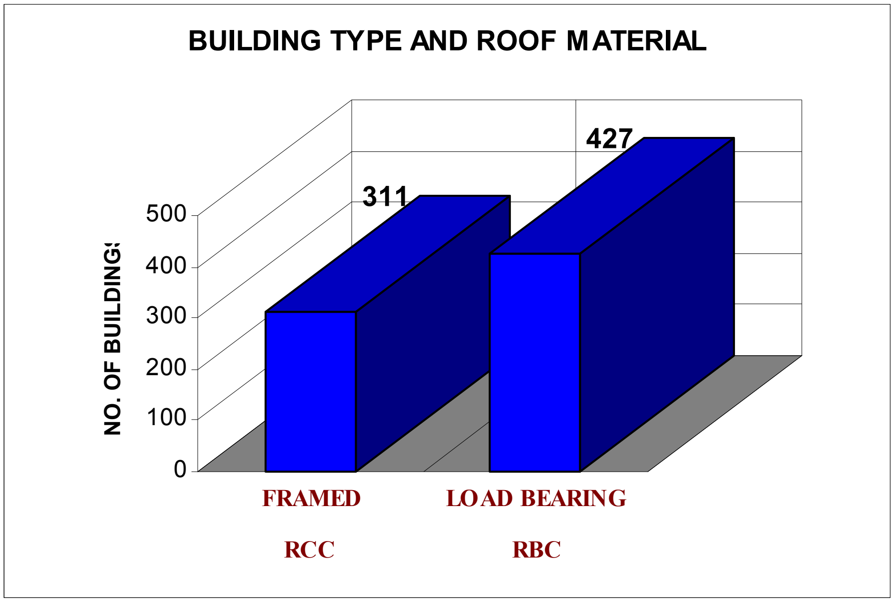


Figure 5-8 Graph showing Building Type and Roof Material

5.3.3 Building Shape

Symmetrical buildings were lesser in number than asymmetrical buildings. 173 houses were symmetrical and 565 houses were asymmetrical (Figure 5-9). The shape of the building is crucial during damage assessment of buildings as asymmetrical buildings tend to be more affected than the symmetrical ones. (Figure 5-10)

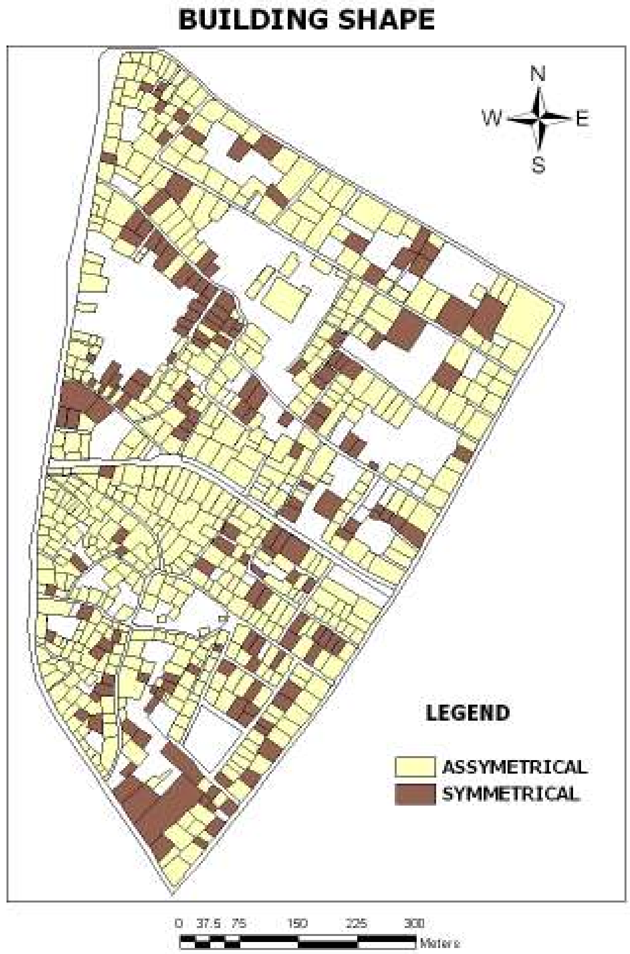


Figure 5-9 Map showing Building Shape

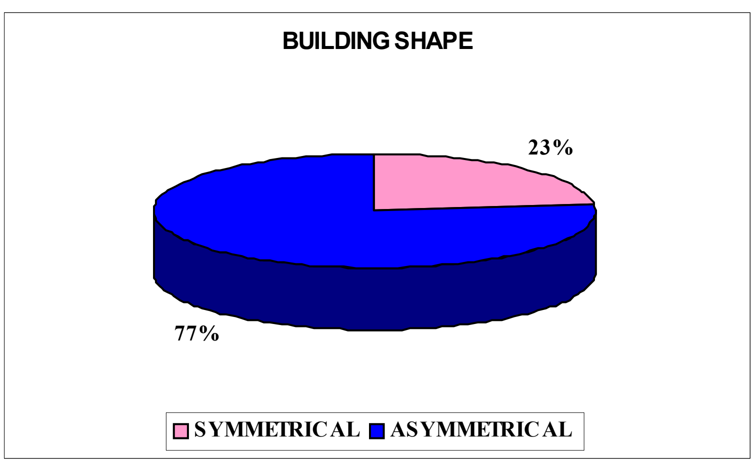


Figure 5-10 Graph showing Building Shape

5.3.4 Building Age

This data was collected through questionnaire survey and it was taken as buildings that aged within 1 year to 20 years were considered to be new ones; the ones that were aged within 20 to 30 were considered as moderately old buildings; and the ones above 30 years were considered as old/very old buildings. Taking this into consideration it was found that, 289 houses were newly built, 317 were moderately old and 132 buildings were very old (Figure 5-11). The age of the building matters as with the passing years the structure, if not well-maintained and constructed, can suffice to excessive damage and lead to a great amount of loss of life and property. (Figure 5-12)

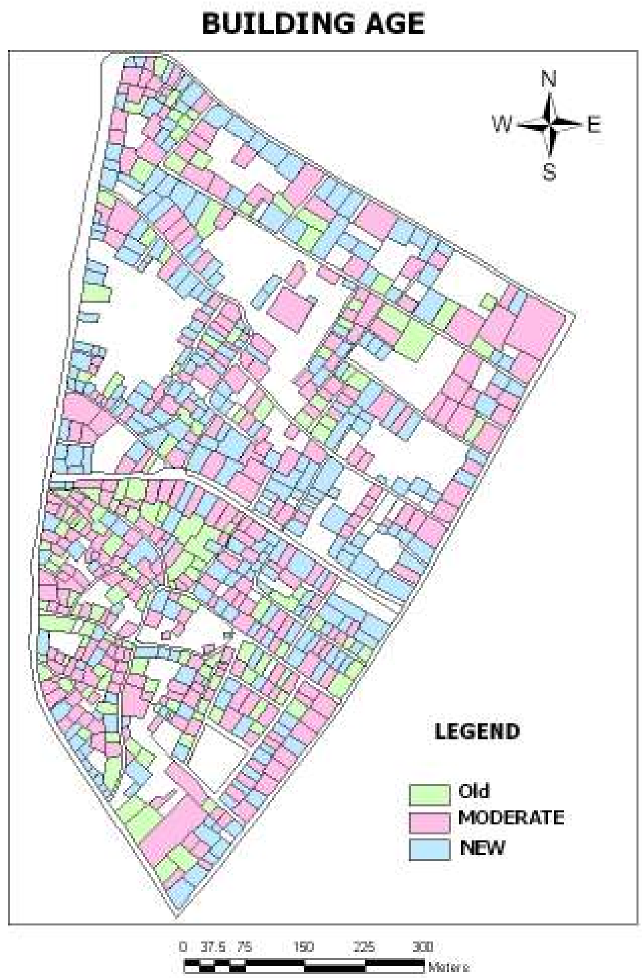


Figure 5-11 Map showing Building Age

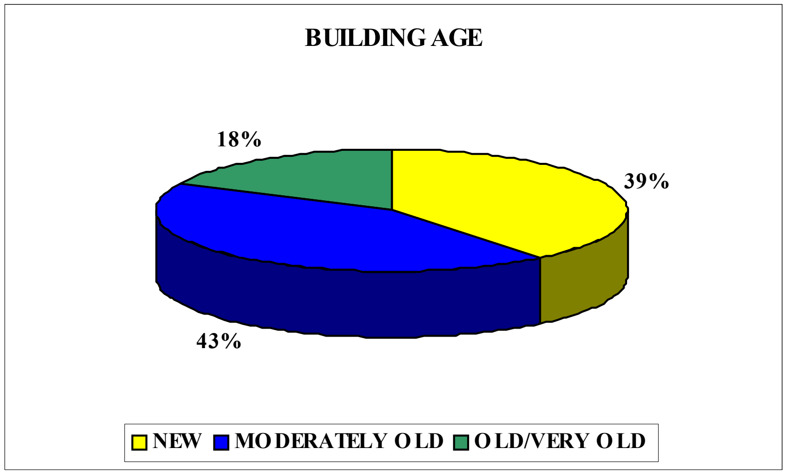


Figure 5-12 Graph showing Building Age

5.3.5 Maintenance

Maintenance of buildings is a very important aspect as it affects the damage that would incur on the building due to lack of it. It has been found that out of 738 buildings surveyed, only 231 buildings were very well maintained, 286 buildings were moderately maintained and 221 buildings were not maintained or were in a very poor state (Figure 5-13). These 221 buildings are risky as at a higher intensity of earthquake these would collapse and there would be an immense loss of life and property. (Figure 5-14)

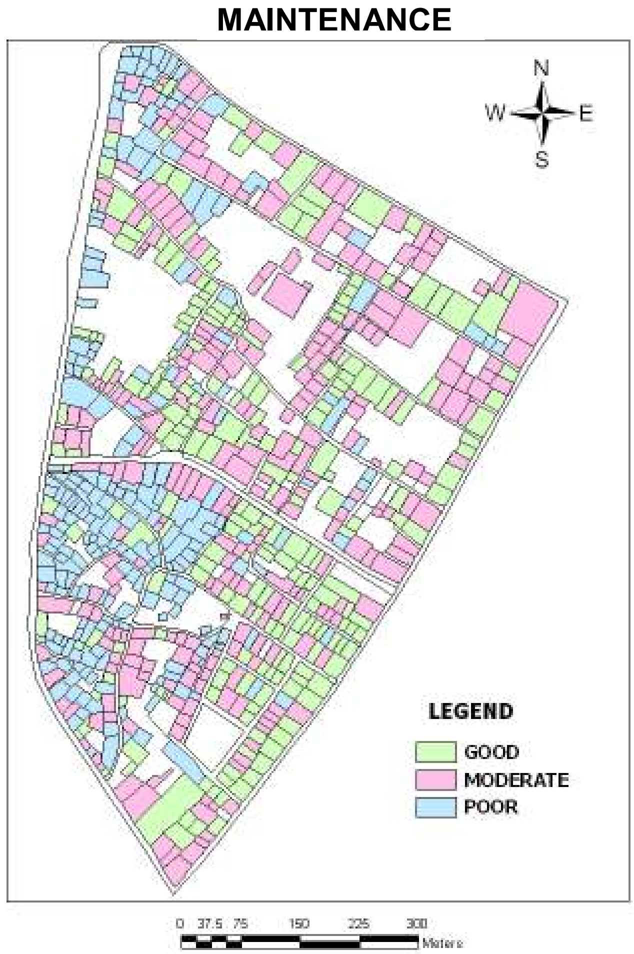


Figure 5-13 Map showing Maintenance of Buildings

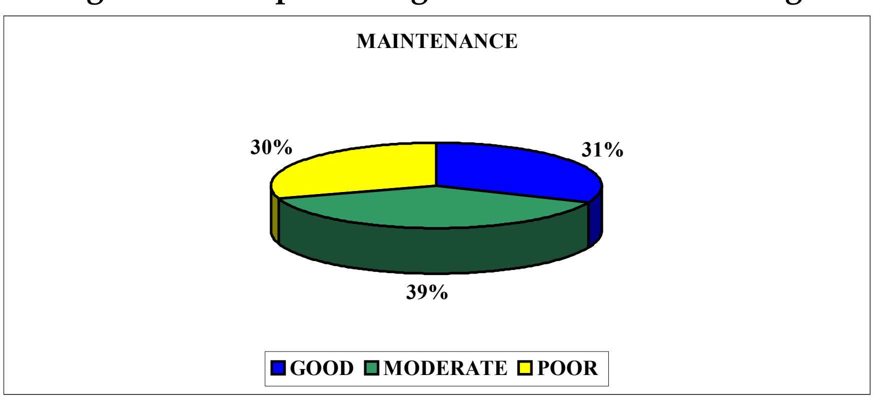


Figure 5-14 Graph showing Maintenance of Buildings

5.3.6 Proximity

Proximity of buildings is another aspect that needs to be considered, as very closely constructed buildings tend to affect their neighboring structures if it is not well maintained and constructed. It was found that 285 houses were within 2 feet of each other, 232 were within 3 feet, 152 were within 4 feet, 32 within 5 feet and 36 houses were within the range of 6 feet to 22 feet (Figure 5-15). The following map shows the proximity of buildings in the area.

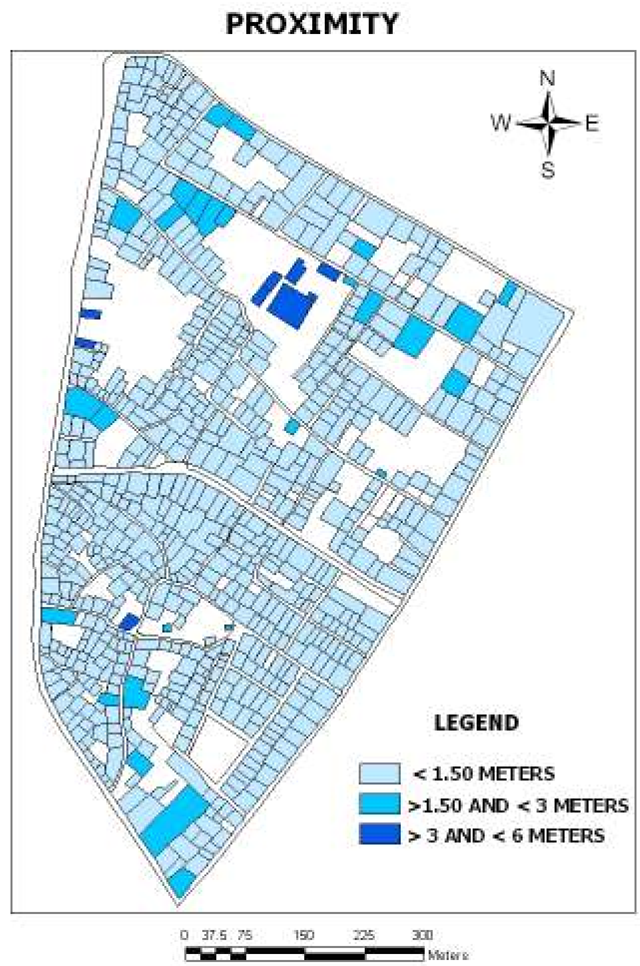


Figure 5-15 Map showing Proximity of Buildings

5.3.7 No. of storeys

Out of the 738 buildings surveyed, 502 buildings have ground floor only and 236 buildings have ground and first floor (Figure 5-16). None of the buildings surveyed had more than 2 storeys primarily because it was a residential area. (Figure 5-17)

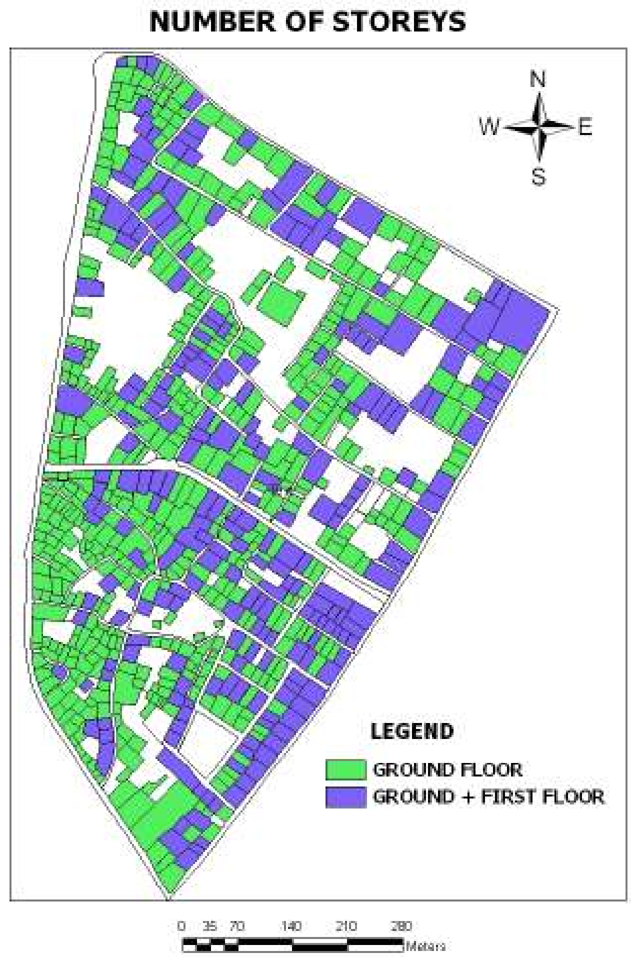


Figure 5-16 Map showing Number of Storeys

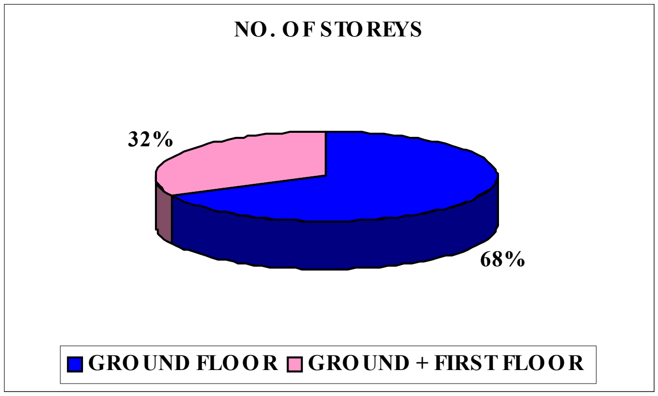
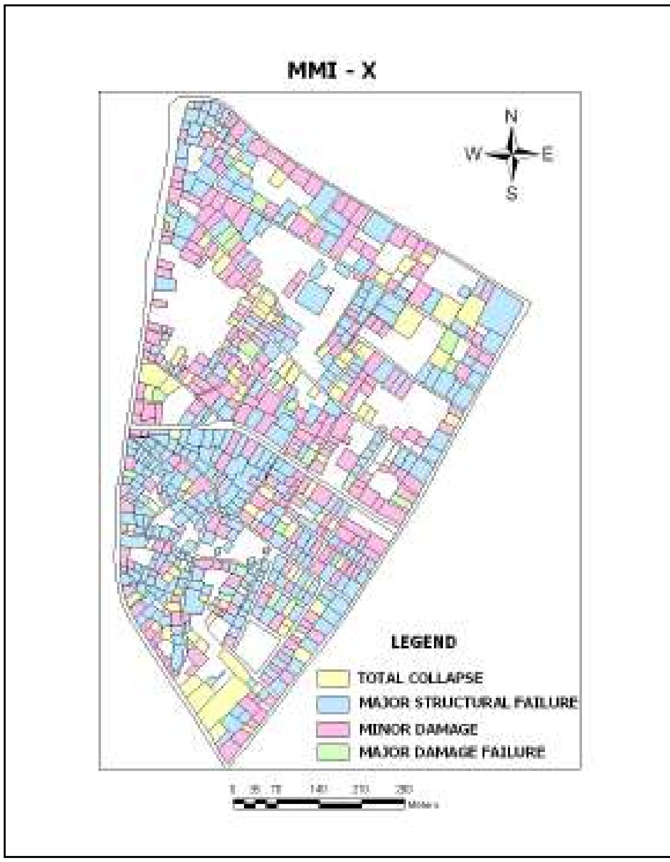


Figure 5-17 Graph showing Number of Storeys

5.4 Building Vulnerability Assessment based on RADIUS methodology

The Damage Probability Matrix was used to evaluate the damage that would occur to different building structures at different earthquake intensities. After preparing the building inventory database, building classes were assigned to each house based on the probability matrix. After the building classes were assigned, it was related to various earthquake intensities like MMI VI, VII, VIII, IX, X and XI. This in turn showed the number of buildings that would have little or no damage at intensity VI, little or no damage and minor damage at intensity VII and VIII, major structural failure, major damage failure and minor damage at intensity IX, along with total collapse at intensity X and finally total collapse, major structural failure and major damage failure at intensity XI.


MMI - VI
LEGEND
LITTLE OR NO DAMAGE
MMI - VII
N
W
E
S
LEGEND
LITTLE OR NO DAMAGE
MINOR DAMAGE
MMI - VIII
N
W
E
S
LEGEND
LITTLE OR NO DAMAGE
MINOR DAMAGE
MMI - IX
N
W
E
S
LEGEND
MAJOR STRUCTURAL FAILURE
MINOR DAMAGE
MAJOR DAMAGE FAILURE



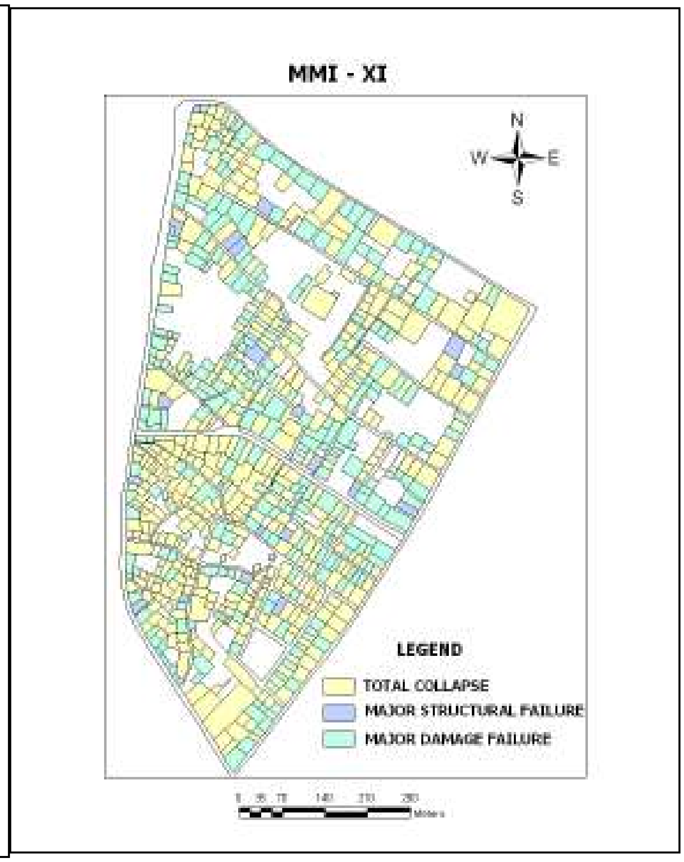


Figure 5-18 Maps showing Building Vulnerability at different MMI

MMI-VII, 312 buildings will have little or no damage and 426 buildings will have minor damage. Thus 42.27% buildings will have almost no damage and the rest 57.7% buildings will have minor damages. (Table 5-1)

At MMI-VIII, 291 houses will have little or no damage, which amounts to 39.4% of the total houses, and 447 houses will have minor damages, which is 60.5%.

At MMI-IX, 329 houses will have major damage failure, 97 houses will have major structural failure and 312 houses will have minor damages. This would amount to 44.5%, 13.14% and 42.2% respectively.

At MMI-X, about 21 houses will have major damage failure, 329 houses will have major structural failure, 291 houses will have minor damage and 97 houses will totally collapse. Thus, only 2.8% houses will have major damage failure, 44.6% houses will have major structural failure, 39.4% houses will have minor damage and the rest 13.14% houses will totally collapse.

At MMI-XI, 426 houses will totally collapse amounting to almost more than half i.e. 57.7% of the total number of houses. 21 houses will have major structural failure and 291 houses will have major damage failure. This would amount to about 2.8% and 39.4% respectively. (Figure 5-18)

MMI	PROBABILITY OF DAMAGE	NO. OF BUILDINGS	(%)
VI	LITTLE/NO DAMAGE	738	100
VII	LITTLE/NO DAMAGE	312	42.276423
	MINOR DAMAGE	426	57.723577
VIII	LITTLE/NO DAMAGE	291	39.430894
	MINOR DAMAGE	447	60.569106
IX	MAJOR DAMAGE FAILURE	329	44.579946
	MAJOR STRUCTURAL FAILURE	97	13.143631
	MINOR DAMAGE	312	42.276423
X	MAJOR DAMAGE FAILURE	21	2.8455285
	MAJOR STRUCTURAL FAILURE	329	44.579946
	MINOR DAMGE	291	39.430894
	TOTAL COLLAPSE	97	13.143631
XI	MAJOR DAMAGE FAILURE	291	39.430894
	MAJOR STRUCTURAL FAILURE	21	2.8455285
	TOTAL COLLAPSE	426	57.723577

Table 5-1 Probability of Damage for Buildings

5.5 Other data relating to population, buildings and roads

5.5.1 Number of persons per House

In the study area, there are 738 houses that have been surveyed, of which the total number of population is 4463. There are 24 houses that have only members living, 48 houses having 3 members, 143 houses having 4 members, 226 houses having 5 members, 58 houses having 6 members and so on (Table 5-2). The mean is about 6 persons per house. (Figure 5-19)

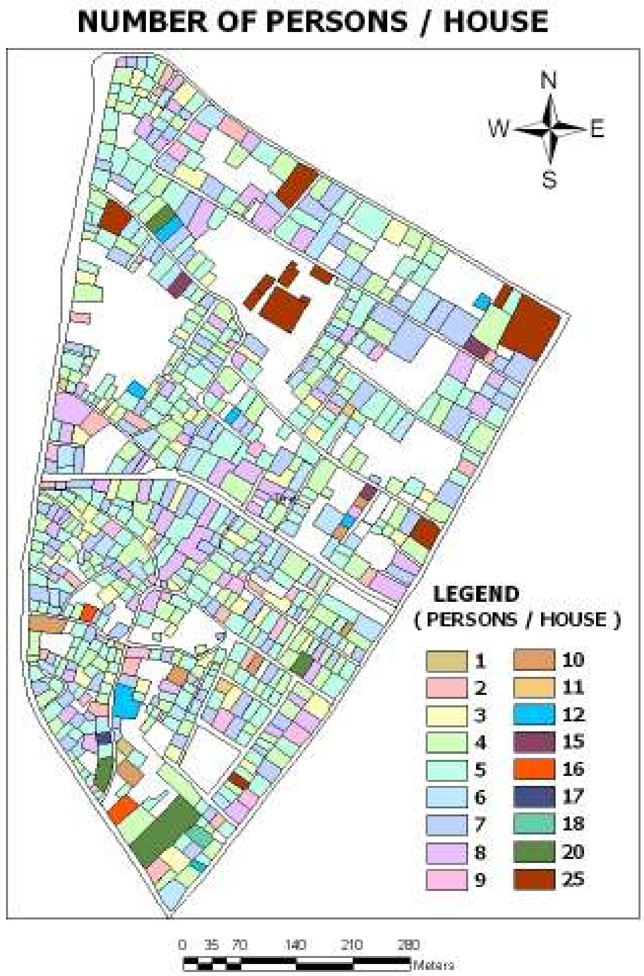


Figure 5-19 Map showing Persons per House

NO OF MEMBERS / HOUSE	NO. OF BUILDINGS
1	1
2	24
3	48
4	143
5	226
6	58
7	113
8	65
9	20
10	7
11	3
12	7
15	3
16	2
17	1
18	1
20	4
25	10
40	1
60	1

Table 5-2 Number of persons per house

5.5.2 Owner or Tenant

Out of all the 738 houses surveyed, 647 have the owners residing in the same building and the other 91 houses have tenants (Figure 5-20). The owners do no reside in these houses except on 2 houses. (Figure 5-21)

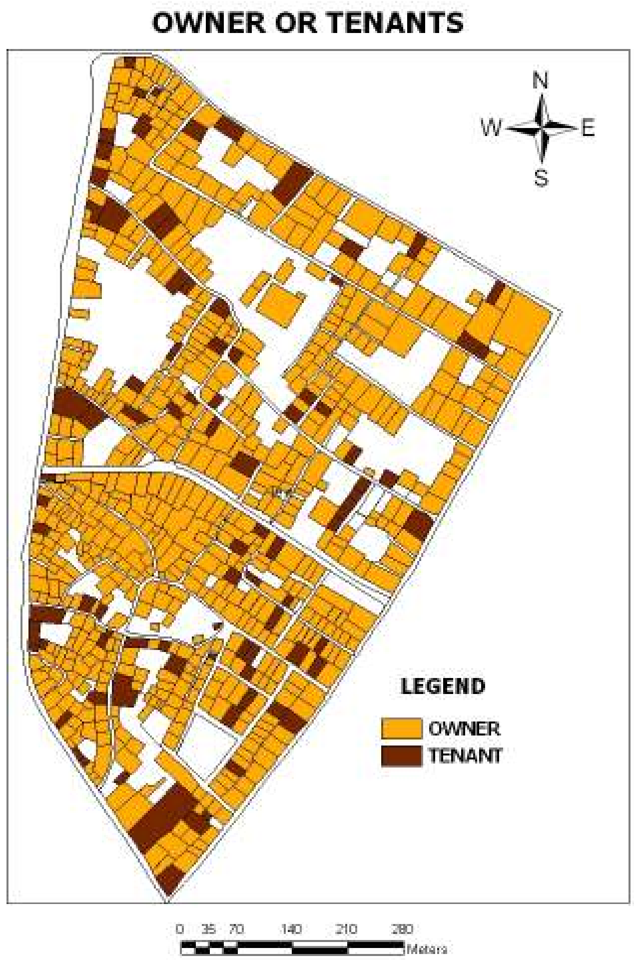


Figure 5-20 Map showing Buildings having owners or tenants

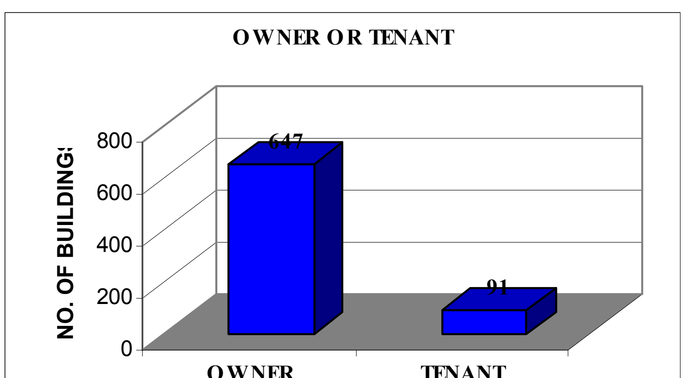


Figure 5-21 Graph showing Owners or Tenants in Buildings

5.5.3 Assets of the people

The assets present in the individual buildings would also be damaged if a very high intensity earthquake hit the area. To evaluate the total amount of assets that would be damaged, data relating to four wheelers, two wheelers, cycle, television, refrigerator, washing machine, cooler/AC and computers were acquired. The following table shows the number of houses having the given assets and what percentage is it out of the total 738 houses that have been surveyed. (Table 5-3)

TYPE OF ASSET		NO. OF BUILDINGS	(%)
FOUR WHEELER	YES	305	41.32791
	NO	433	58.67209
TWO WHEELER	YES	538	72.89973
	NO	200	27.10027
CYCLE	YES	422	57.18157
	NO	316	42.81843
TELEVISION	YES	660	89.43089
	NO	78	10.56911
REFRIGERATOR	YES	664	89.9729
	NO	74	10.0271
WASHING MACHINE	YES	345	46.74797
	NO	393	53.25203
COOLER/AC	YES	134	18.15718
	NO	604	81.84282
COMPUTER	YES	64	8.672087
	NO	674	91.32791

Table 5-3 Assets per building

From this we can analyze the amount of property damage that would occur in the study area if an earthquake of MMI – X and XI occurs. When relating this to the number of buildings that would collapse, it has been found that at MMI – X, the total number of buildings that would totally collapse would be 97 houses of which 74 houses have two wheelers, 36 houses have four wheelers, 53 have cycles, 90 have television, 90 have refrigerator, 50 have washing machines, 15 have AC/Cooler and 6 houses have computers. At MMI – XI, the total number of buildings that would collapse would be 426, 178 houses have four wheelers, 317 have two wheelers, 235 have cycles, 384 have television, 384 have refrigerators, 185 have washing machines, 72 have AC/Cooler and 38 houses have computers. This gives an idea of the amount of property damage that would occur in the area if a very high intensity earthquake hits. This would amount to a great economic loss. If this statistic can be formulated in terms of prices then lakhs and crores of rupees would be damaged. (Figure 5-22)

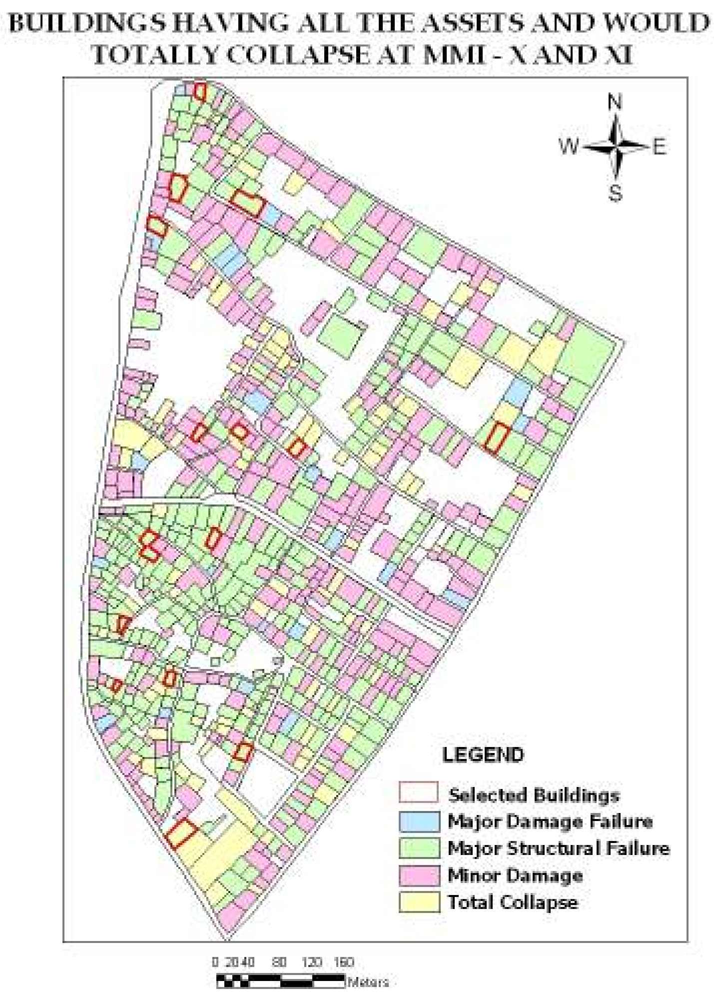


Figure 5-22 Relation of Buildings with Assets

5.5.4 Road type

There are 22 bylanes in the study area, 22 secondary roads and 2 primary roads. The primary roads is the Haridwar road on the left side of the study area; Balbir road branching out of it on the other side and the area is divided into two halves by the Canal road. (Figure 5-23)

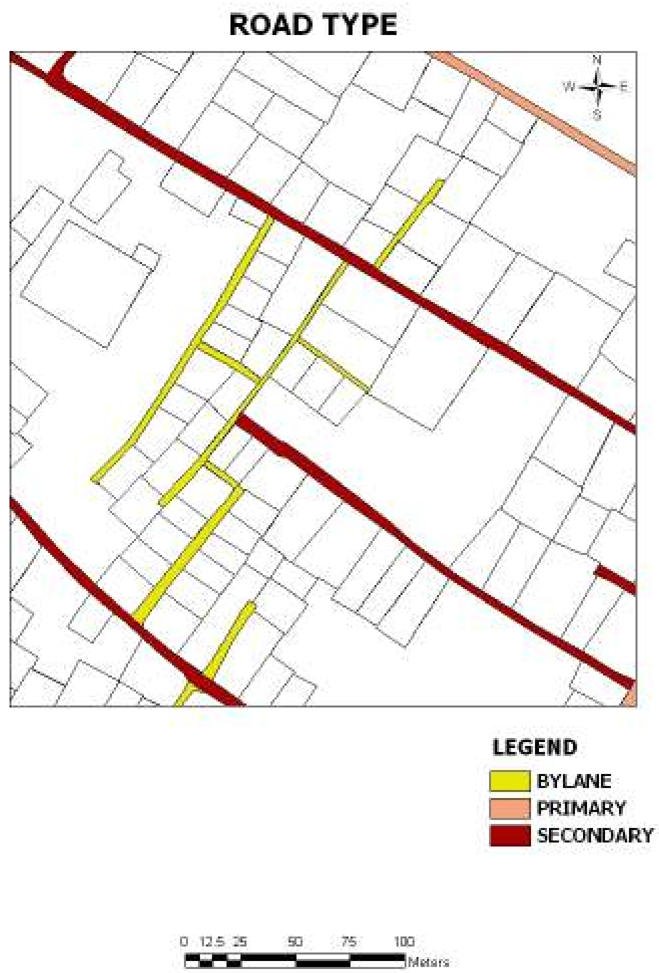


Figure 5-23 Map showing Road Type

5.5.5 Road width

All the bylanes are 3 meters in width, secondary roads are 5 meters and primary roads are 6 meters. A distinctive thinning of roads has occurred since 2000, and this was seen clearly while digitizing the 2005 image. (Figure 5-24)

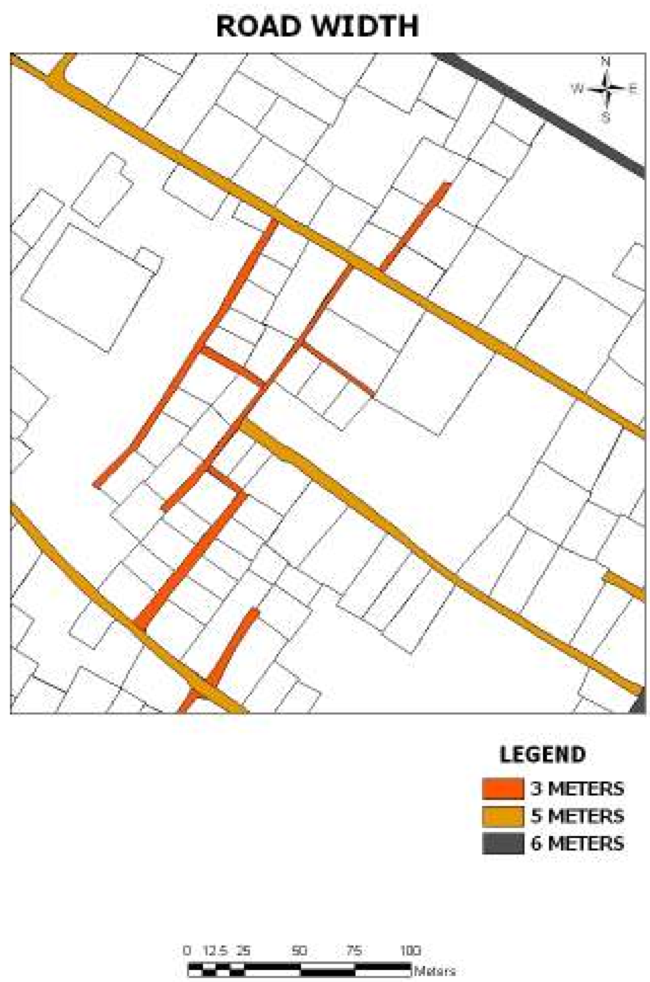


Figure 5-24 Map showing Road Width

5.5.6 Road material

Out of all the roads in the study area, only 29 roads are made of asphalt and 17 roads are made of non-asphalt. Though the area tends to be a planned area, certain aspects of the area have not been taken in consideration. Asphalt roads that are well-connected and wide roads need to be made in the area. (Figure 5-25)

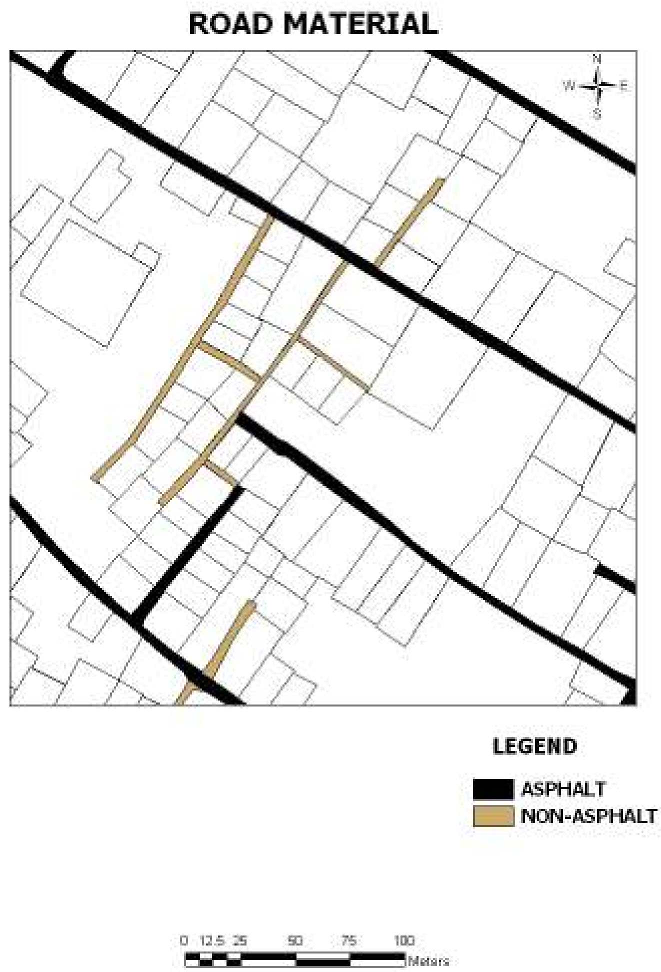


Figure 5-25 Map showing Road Material

5.6 Buildings affecting roads at different earthquake intensities

During an earthquake, buildings would be affected and this in turn would lead to road blockage. Buffers have been made around the roads of the area and the number of buildings that would affect has been calculated. (Table 5-4)

Table 5-4 Buildings affecting roads at different earthquake intensities

BUFFER AROUND ROADS (IN METERS)	MMI - VI
	LITTLE/NO DAMAGE
3	165
5	392
6	149

BUFFER AROUND ROADS (IN METERS)	MMI - VII	
	LITTLE/NO DAMAGE	MINOR DAMAGE
3	65	100
5	160	232
6	80	69

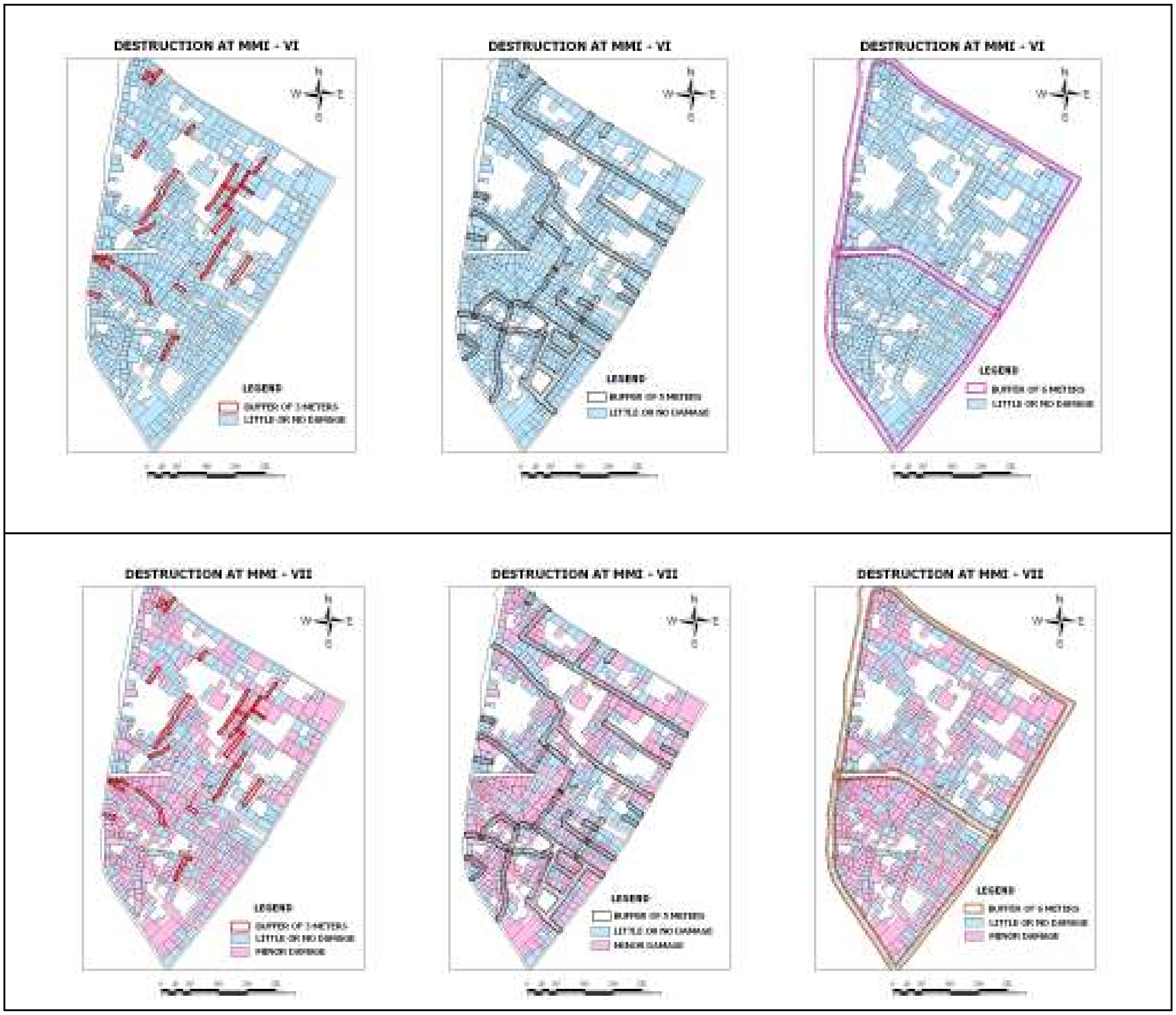
BUFFER AROUND ROADS (IN METERS)	MMI - VIII	
	LITTLE/NO DAMAGE	MINOR DAMAGE
3	63	102
5	147	245
6	75	74

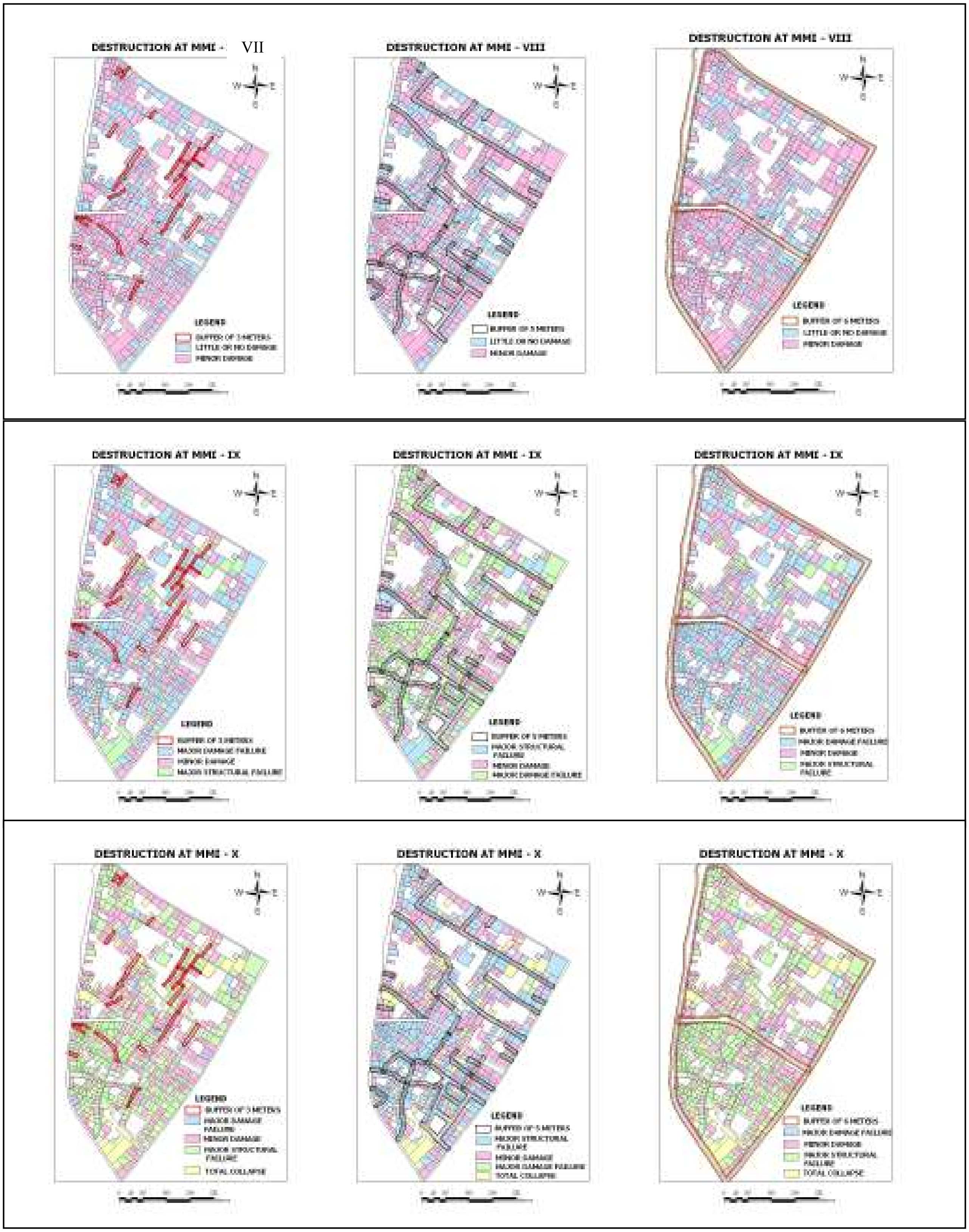
BUFFER AROUND ROADS (IN METERS)	MMI - IX		
	MAJOR DAMAGE FAILURE	MAJOR STRUCTURAL FAILURE	MINOR DAMAGE
3	74	26	65
5	181	51	160
6	58	10	72

BUFFER AROUND ROADS (IN METERS)	MMI - X			
	MAJOR DAMAGE FAILURE	MAJOR STRUCTURAL FAILURE	MINOR DAMAGE	TOTAL COLLAPSE
3	3	74	62	26
5	13	181	147	51
6	5	59	75	10

BUFFER AROUND ROADS (IN METERS)	MMI - XI		
	MAJOR DAMAGE FAILURE	MAJOR STRUCTURAL FAILURE	TOTAL COLLAPSE
3	62	3	100
5	147	13	232
6	75	5	69

From the above tables, it can be evaluated that around the 3-meter roads, there are totally 165 houses, 392 round the 5-meter roads and 149 houses around the 6-meter roads. At intensities VI, VII and VIII, there would not be any form of road blockage but at intensities IX, X and XI, the roads would be blocked due to major damage failure, structural failure and for some houses, total collapse. This would aggravate the situation, as relief would not be possible to provide to all the houses and their members. The mostly affected roads would be the 3-meter ones, which provides link to 165 houses. If an earthquake intensity of IX, X or XI occurs, then many houses that would be affected, would eventually cause blockage of roads. For example, at intensity X, around 26 houses would totally collapse and at intensity XI, 100 houses would collapse. This would affect the 3-meter roads and emergency relief would be difficult to provide in these places.




DESTRUCTION AT MMI - VII
LEGEND
BUFFER OF 3 METERS
LITTLE OR NO DAMAGE
MINOR DAMAGE
DESTRUCTION AT MMI - VIII
LEGEND
BUFFER OF 5 METERS
LITTLE OR NO DAMAGE
MINOR DAMAGE
DESTRUCTION AT MMI - VIII
LEGEND
BUFFER OF 6 METERS
LITTLE OR NO DAMAGE
MINOR DAMAGE
DESTRUCTION AT MMI - IX
LEGEND
BUFFER OF 3 METERS
MAJOR DAMAGE FAILURE
MINOR DAMAGE
MAJOR STRUCTURAL FAILURE
DESTRUCTION AT MMI - IX
LEGEND
BUFFER OF 5 METERS
MAJOR STRUCTURAL FAILURE
MINOR DAMAGE
MAJOR DAMAGE FAILURE
DESTRUCTION AT MMI - IX
LEGEND
BUFFER OF 6 METERS
MAJOR DAMAGE FAILURE
MINOR DAMAGE
MAJOR STRUCTURAL FAILURE
DESTRUCTION AT MMI - X
LEGEND
BUFFER OF 3 METERS
MAJOR DAMAGE FAILURE
MINOR DAMAGE
MAJOR STRUCTURAL FAILURE
TOTAL COLLAPSE
DESTRUCTION AT MMI - X
LEGEND
BUFFER OF 5 METERS
MAJOR STRUCTURAL FAILURE
MINOR DAMAGE
MAJOR DAMAGE FAILURE
TOTAL COLLAPSE
DESTRUCTION AT MMI - X
LEGEND
BUFFER OF 6 METERS
MAJOR DAMAGE FAILURE
MINOR DAMAGE
MAJOR STRUCTURAL FAILURE
TOTAL COLLAPSE

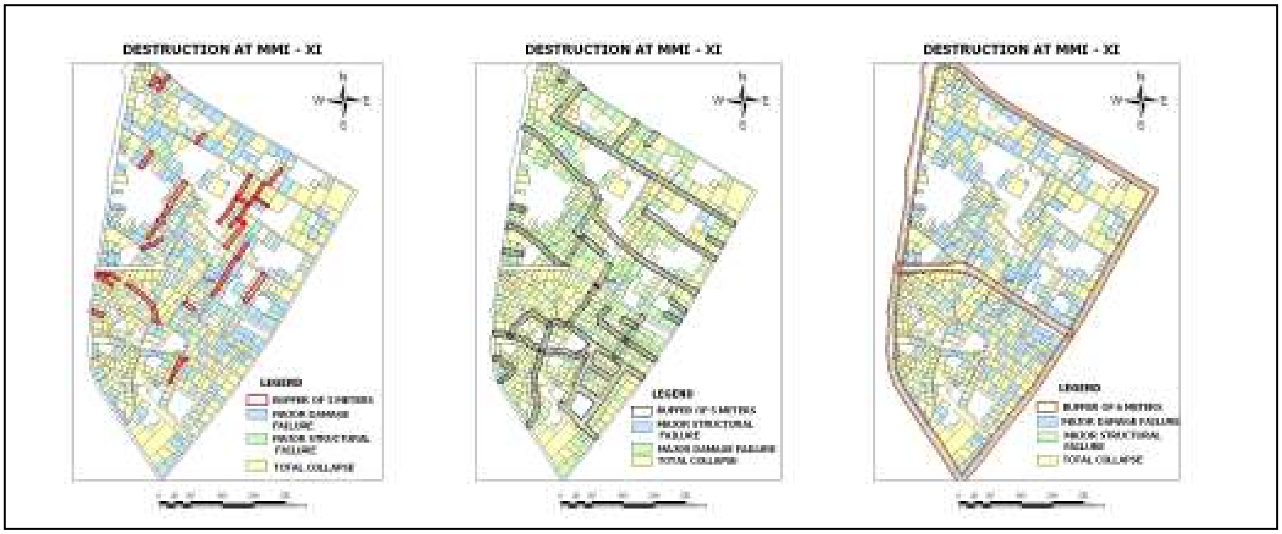


Figure 5-26 Maps showing Buildings affecting Roads at different Earthquake Intensities

5.7 Assessment of Population at Risk

Buildings, population, lifelines are the main aspects under the impact of risk. Population is directly affected and this in turn causes huge amount of damage. In this research, population at risk in the study area has been calculated. Only at MMI – X and XI, there are houses that would totally collapse, and people living in these houses would be at maximum risk. (Table 5-5)

TOTAL POPULATION (DAY TIME)	POPULATION AT RISK (DAY TIME)	TOTAL POPULATION (NIGHT TIME)	POPULATION AT RISK (NIGHT TIME)
2865	2131	4047	2865

Table 5-5 Population during daytime and nighttime

From the above table, it is evaluated that of 2865 people living in the area, 2131 of them are at risk at intensity X and XI, during the day. Out f 4047 people living in the area during nighttime, 2865 of them are at risk at intensity X and XI. Only these two intensity scenarios have been taken into consideration, as there is total collapse of buildings during these intensities. (Figure 5-27)

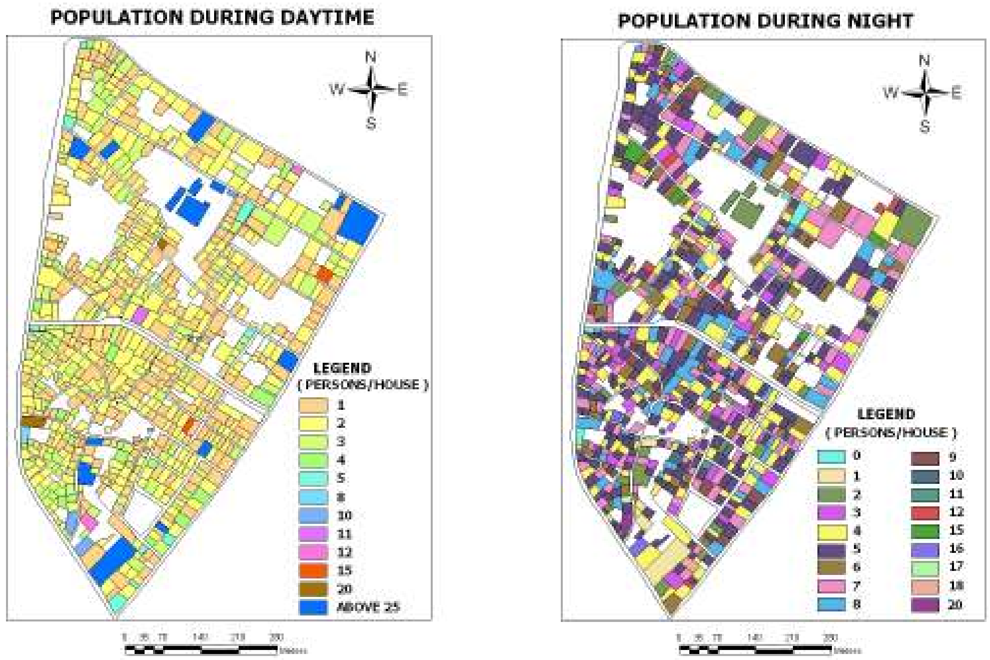


Figure 5-27 Maps showing Population during Day Time and Night Time

The above maps show the distribution of population at different buildings during daytime and nighttime. Thus, in this part the risk of population is estimated for major building use in the study area with respect to total population for both daytime and nighttime earthquake scenarios. The percentage of population at risk during daytime would be 74% and during nighttime would be 70%. The people are at a higher risk during the daytime and this is mostly because of the various offices, commercial and educational buildings that are mainly affected.

5.8 Query based analysis of database

Various query-based analysis can be made in a GIS environment. Spatial data analysis is made easier with the help of GIS technology and if a database is created which has ample information of individual buildings in an area then, this is highly useful for various urban planners, policy makers, local authorities and planning agencies. They are able to utilize this data in formulating various strategies and finding solutions in case of emergencies.

Query 1

A very striking aspect of this area has been revealed when a query was made to find out those specific buildings that are residential, having very close proximity within buildings, with the building shape being asymmetrical, maintenance being moderate to poor, older or moderately old buildings with load bearing structure and RBC roof material. It showed that there are a total 463 houses that fall within this category and the maximum concentration of these buildings are in the central western part of the study area and a few concentrations in the northern part of the study area. (Figure 5-28)

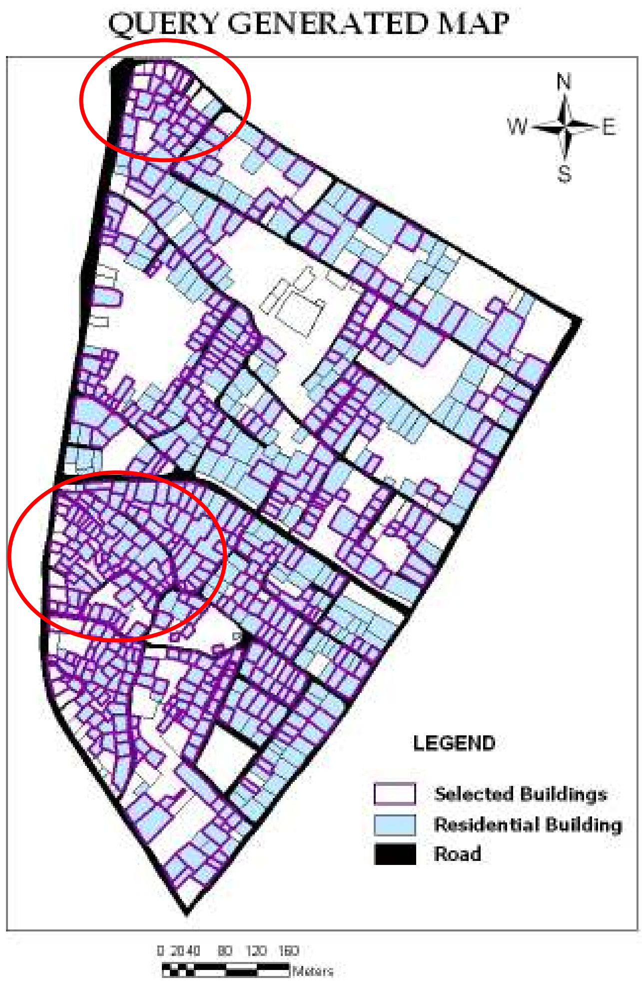


Figure 5-28 Map showing vulnerable buildings in the study area

The northern part falls within Dalanwala South ward and the central western part is within Dharampur ward. These are the buildings that are mostly vulnerable and are at higher risk during an event of an earthquake. It is also quite prominent that the southern part of the study area, which falls within Dharampur, has a more congested form of building structures and these are not planned in a proper way. Illegal constructions have been found in these area and the roads are thin and winding. All these aspects effect building vulnerability to a great extent.

Query 2

A second query was made to identify those buildings that were residential in nature, having proximity between buildings more than 4 feet, symmetrical structures which are new and well maintained with framed structures and RCC roof materials. It has been found that there are only 209 houses that fall within this category. It is distributed all over the study are and the number of buildings are more in the northern part than in the southern part. This is mostly because of the fact that Dalanwala South ward is better planned than Dharampur ward.

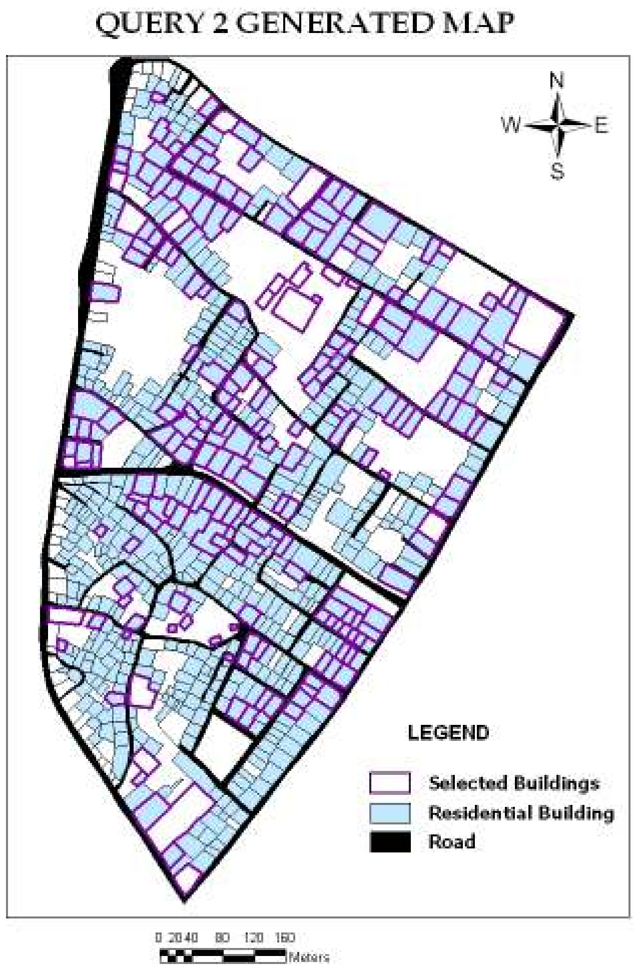


Figure 5-29 Map showing buildings that are comparatively less vulnerable during an earthquake

Query 3

A query has been generated to single out those buildings whose owners reside in the same building and these buildings have all the assets, namely, four wheeler, two wheeler, cycle, television, refrigerator, washing machine, AC/cooler and computer. It has been found that only 28 houses have all these in the total study area. This would be an indication to the economic level of the people staying in the area and it shows that the affluent people are very less numbered. (Figure 5-30)

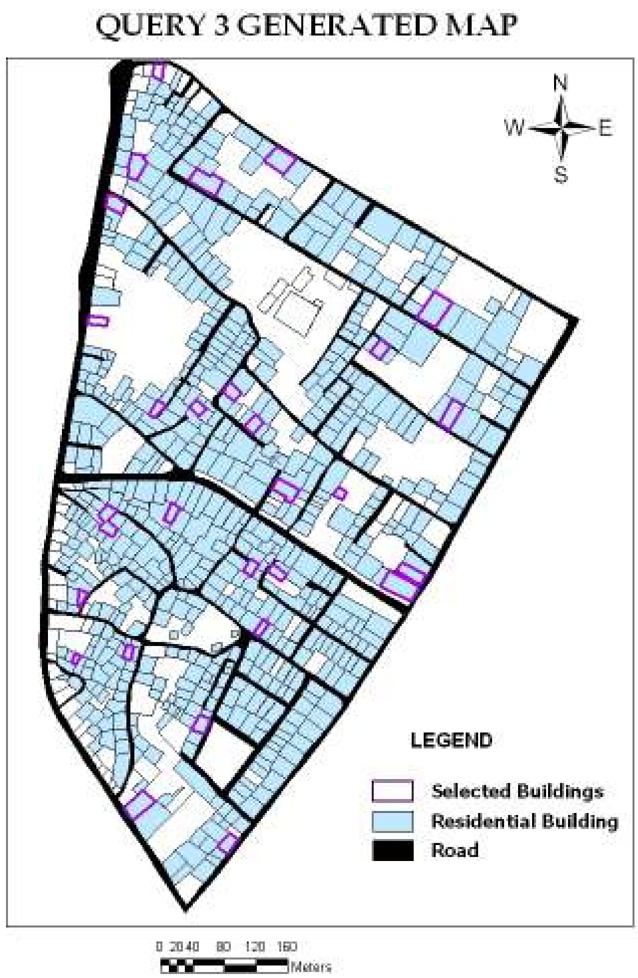


Figure 5-30 Map showing Buildings having their Owners residing in the same and also having all the given assets

Query 4

A fourth query has been generated to relate occupation of the main member of the house to the building attributes. Those houses which are asymmetrically shaped, with moderate to poor maintenance, load bearing structures with RBC roof material and moderately old to very old houses having the main male member of the family in the service sector, have been singled out. About 563 houses fell in this category, which was an overwhelming number amounting to about 76% of the total buildings. (Figure 5-31)

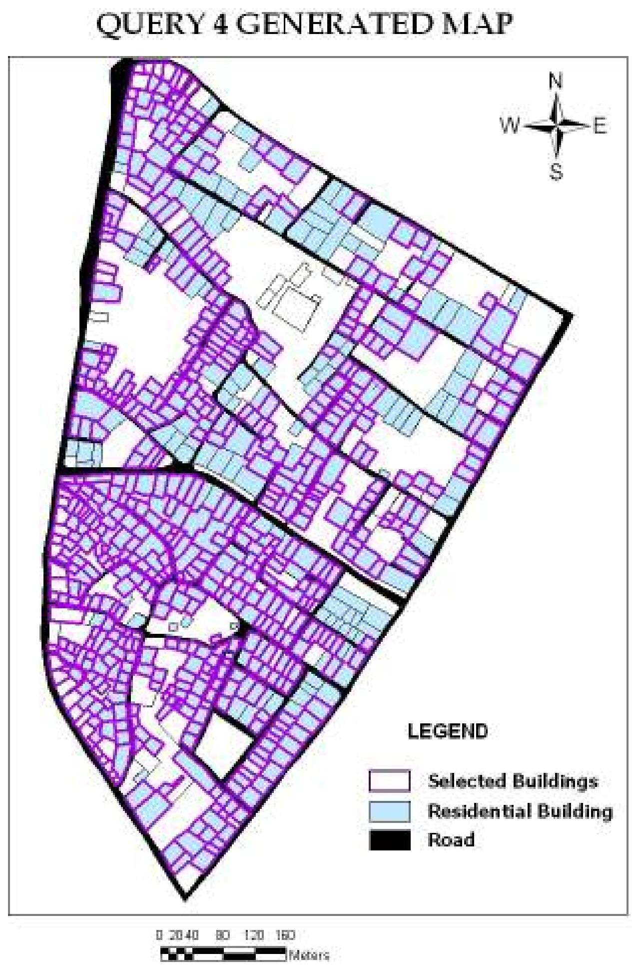


Figure 5-31 Map showing relation between Occupation and Building Attributes (1)

Query 5

A fifth query was made to find out all those buildings, which were poorly maintained with load bearing structures and RBC roof materials, asymmetrically shaped, moderately old to very old ones having the main male member of the family in the business sector. It showed that there were about 584 houses and most of these buildings were present in the southern part, Dharampur ward. (Figure 5-32)

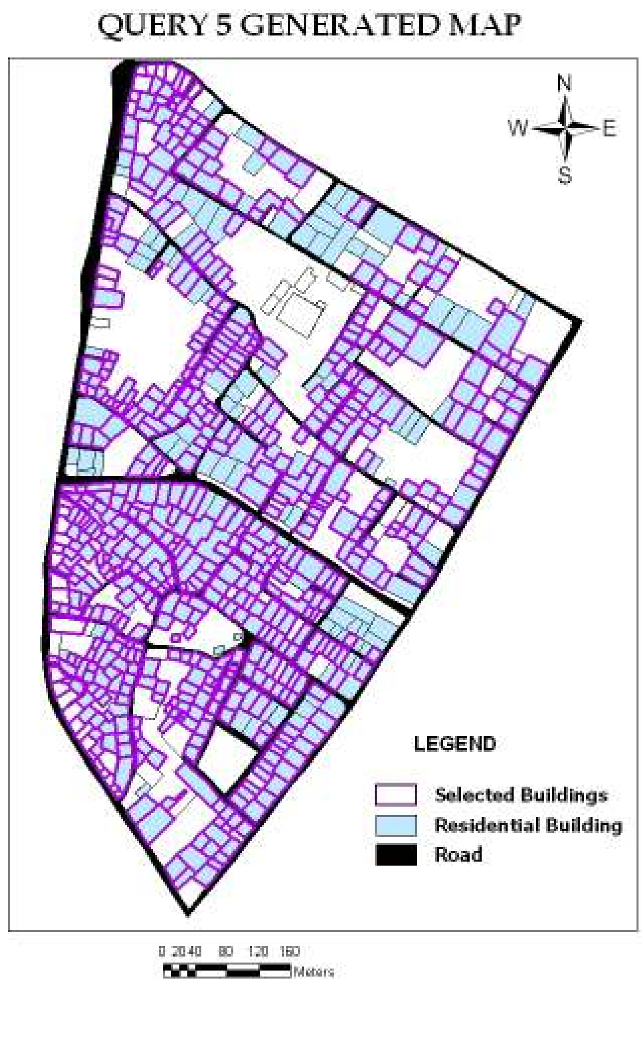


Figure 5-32 Map showing relation between Occupation and Building Attributes (2)

In this way various queries can be made and maps can be generated. GIS is a very useful tool in this regard and can be extensively used to visually interpret and analyze situations and scenarios. All spatial data can be then represented in the form of maps and this makes it easier for even a layman to understand. This type of analysis is highly useful for urban planners and policy makers and even the local authorities. Though the data collection may be difficult in Indian scenario but once the database has been made, proper analysis for damage estimation during a crisis can be made very easily.

Chapter 6

6. Conclusions and Recommendations

This chapter discusses the conclusion drawn from the study carried out and provides recommendations for safety and mitigation measures.

6.1 Conclusions

"Urban vulnerability to natural hazards such as earthquakes is a function of human behavior. It describes the degree to which socioeconomic systems and physical assets in urban areas are either susceptible or resilient to the impact of natural hazards" Rashed et al. (2003) In addition to the disaster preparedness, satellite imagery can serve as a source of information in acute emergency, crisis or disaster situation. Earth observation can successfully provide a beneficial support of disaster management, humanitarian relief and civil security. It was shown how satellite imagery could be acquired, assessed, processed and turned into information products for decision makers. It is of primary importance that the space technology provides easy to use and ready to access information solutions to the relief community.

The outputs of the GIS based analysis as well as the community-based approach of building vulnerability assessment is useful for obtaining a wider array of results which can be beneficial to the Urban Local Body when it comes to actual identification of buildings that need to be identified as requiring attention. Population distribution varies and fluctuates to a great extent during different hours of the day and in various buildings occupancy types. Hence Census sources are outdated as well inadequate as well as relatively outdated for vulnerability analysis. Since Dehradun became the capital city of Uttaranchal, population has increased at a remarkable rate and this in turn has led to many building constructions. At times these constructions were made in an unplanned way and this increases the vulnerability risk of the buildings during an earthquake. Dehradun falls within zone one of earthquake and thus is very vulnerable to this hazard. Therefore, proper mitigation measures should be taken in order to safeguard the people and property of the area and this can be made possible with the collaborative effort of the community, local authorities and government.

GIS and remote sensing technology has helped immensely in detecting hazard zones and evaluating vulnerable areas. Based on this mitigation measures can be made easily. Remote sensing is a tool used for spatial data acquisition and GIS helps in using these spatial data and representing it in a way which would be valuable for formulating strategies by the planners and the various local authorities.

This research in part of Dalanwala South and Dharampur ward has shown that Dharampur area has more vulnerable buildings than that of Dalanwala South ward. Thinning of roads and unplanned building construction has increased the vulnerability of the area and people and property are at a greater risk.

In order to answer the various research questions, it has been found that urbanization has occurred in a great extent over the past five years. In the study area it has been found that every year, for the past 5 years, about 25 new constructions have been made and if this continues then urban densification will take place at an alarming rate in the next decade. This would lead to complexities relating to population and building vulnerability. Remote sensing helped to analyze the number of constructions that have been made over the years but a more authentic value was given with the help of field survey.

A detailed analysis of the impact earthquake would have on various types of buildings have been made with the help of RADIUS method of analysis. This is quite easily applicable in the Indian scenario, but the accuracy at times would be time dependant and also dependant on the amount and accuracy of data that is collected. In the Indian context, presence of readily available data is negligible. Thus, every time a research study is carried out, database creation takes up quite some time. Yet it was found that Dharampur is at a more vulnerable state than that of Dalanwala South. Proper measures should be taken by the local authorities in order to save to life and property of this area.

The various building parameters that have been used in this study for earthquake vulnerability study included building type, roof material, proximity, building age, building shape and maintenance. These parameters are crucial in evaluating vulnerability of buildings.

Location and quantification of vulnerable buildings have been done with the help of GIS technology. It was wade much easier to handle the data collected and a comparative analysis of the two parts of the ward was made in a more detailed and accurate manner.

Population at risk is another aspect that was taken into consideration in this study. Daytime population and night time population data was collected and based on the effect of earthquake intensity on buildings, those people who would be more vulnerable have been evaluated. These buildings should, thus, be given priority.

Due to the expansion of the urban areas, roads have thinned down and buildings have extended illegally on the roads. This would have a huge impact, as emergency relief would be difficult to provide to areas, as roads would be blocked if there were total collapse of buildings. Thus, in this study, how buildings would effect roads have been evaluated and these areas need to be looked at. Road maintenance and road width need to be reevaluated and proper measures need to be taken. In Dharampur ward, the roads are narrow and winding, with close-knit buildings with very less space has been found. These areas are prone to high risk during an earthquake and if an earthquake of MMI-X or XI occurs, there would be many buildings in this area that would totally collapse and this would block the roads. Relief would be difficult to reach in these areas and so proper measures need to be taken as early as possible.

6.2 Recommendations and Mitigation Measures

A systematic, comparative assessment of earthquake risk can be useful for raising the awareness of earthquake risk among local officials and the public, and for resource allocation among cities. The project results can be helpful both in providing the final risk-based rankings and in offering a framework for systematic discussion of the issues associated with earthquake risk and risk management.

A major way in which loss of life and injury can be reduced in a major earthquake is by undertaking a nonstructural vulnerability assessment. This involves a visual inspection of each room of a property to identify furniture and fittings that could topple or break in the event of an earthquake and cause injury and/or restrict access to exits, trapping the occupants. Even relatively simple and cheap measures have been demonstrated to reduce vulnerability significantly. In addition to reducing injury and damage it helps to retain the functionality of properties and reduces the period required for return to normal activity. This also eases pressure on external resources - hospitals are better able to cope with the serious cases, as there are fewer other injuries to treat - and it means that there are more able-bodied people available to help with post-event recovery and reconstruction.

The basic tenets of mitigation are:
- Do not increase existing risk (i.e. build properly);
- Decrease existing risk (i.e. retrofit) and;
- Transfer risk (i.e. buy insurance).

The reduction of structural vulnerability, siting and land-use regulations, design and construction regulations, relocation of communities, and public education/awareness programs are viable measures for the mitigation of earthquake risk. Urban settlements can be improved by changing the functional characteristics of settlements through land-use planning and increasing the redundancy of infrastructure, such as building an additional bridge at a strategic crossing.

Improvements over existing buildings are very important. In order to do so, application of the new earthquake resistant design code should be applied, increase public awareness and demand for earthquake safety, provide various training and education programs for engineers, better zoning regulations and enforcement by municipalities and also allow control by private construction supervision firms. In India, the most important and complex issue in mitigating earthquake casualties is the retrofitting of existing buildings.

The most effective way to reduce human casualties is through the retrofit of existing building stock. Although several assessments and retrofit applications are in place for public and commercial buildings, serious initiatives have yet to be taken for the strengthening of residential building stock. A comprehensive retrofit campaign will be a formidable task that would involve the earthquake performance screening of many buildings, prioritization based on the exhibited risk, analysis of options and market study, development of retrofit alternatives; development engineering capacity for retrofit and finally creation of public / private incentives.

The full retrofit (i.e. in compliance with the latest code requirements) of a residential building requires that the building be vacated for several months. In addition to this high cost and the inconvenience of moving from residential buildings, there are strong impediments to retrofitting. The retrofit decision is difficult to reach since these buildings are multi-family owned/rented apartments with tenants having different expectations, budgets, and constraints. Due to high residential mobility, people do not want to spend money if they may be moving. Furthermore, there is evidence that retrofitting is an investment without financial return since it does not increase a property's sales value or rental fee. Under these conditions, no conceivable reduction in insurance premium (or property tax) would be sufficient to create an incentive for retrofitting.

Possible incentives for retrofitting are being discussed all over the world, however. These include:

- Earthquake retrofit grants by government or compulsory insurance agencies;
- Below-market interest rates on loans for earthquake retrofit;
- Insurance premium discounts to policyholders upon completion of the retrofit and; financial incentives to property owners of properties, such as, waiving of building permit fees, city property taxes and easing of siting and geometric regulations.
- Although building owners will find future property losses small by comparison with the cost of a full retrofit and cannot visualize the benefit, at the macro scale, society in general will greatly benefit from a retrofit campaign through a reduction in physical, social and societal losses that will eventually have to be covered by the general population.

The objective of retrofitting would be the avoidance of total building collapse. The earthquake performance criteria would be the prevention of total collapse and saving lives at minimum cost. The avoidance of total and pancake-type collapses is also important for facilitating search and rescue operations and reducing road closures. However, it should be noted that the boundary between upgrades to "collapse prevention" and "life safety" performance criteria is fuzzy and more research is needed to assess the amount of retrofit consistent with the objective of saving lives at minimum cost.

6.2.1 Pre Earthquake Mitigation Measures

- It is always more cost effective to adopt appropriate mitigation measures in advance than to spend a large sum of money on relief, recovery and rehabilitation. The following measures should be considered before the occurrence of major event in the region:
- Seismo-tectonic and seismic hazard microzonation maps of the region need to be prepared. This will help in locating the seismogenic faults and other potential sources of earthquakes and also in delineating high seismic risk areas in the region.
- The rate of population growth in the region is very high and expansion of many cities in the region is unplanned and unscientific. This has increased the vulnerability of life and property to seismic hazards manifold. The loss of life and property damage would be enormous if the major earthquakes strike the

region now. Thus vulnerability under different levels of ground motions and risk evaluations has become essential.

It is not the earthquake themselves that kill people but the collapse of man-made structures which does most of the damage. Therefore, devastation caused by an earthquake depends more on whether buildings have followed buildings norms or not. Suitable building codes as recommended in the latest BIS notification (IS 13828:1993) should be adhered to while constructing structures in the region. These along with the Landuse restrictions should be incorporated in the Town and Country Planning laws and in the Municipal by-laws. Many cities in the region are expanding in the hazard prone areas in the absence of these laws and by-laws. The "Assam Type Structure" which were flexible and sufficiently earthquake proof have paved the way for multistory masonry buildings particularly in the capital towns of northeastern states. Normally, houses and other structures are built to withstand vertical load only and as a result they collapse when subjected to horizontal stresses produced by seismic waves. The main requirements for preventing the collapse are a lateral load carrying system of enough residual capacity to safely resist lateral forces, a monolithic roof with sufficient in-place rigidity and a strong and durable vertical load carrying system (Shukla, 1998). It is experienced that the buildings made after 1981 (that followed a seismic designing) had no damage during Kobe event of Japan (Struck, 1999).

- The detection capability of seismic instruments needs to be improved upon and the seismic network in the region has to be strengthened.
- Effective communication, warning and response system have to be developed along with the action plan.
- Preparedness for seismic hazard involves sound emergency evacuation, relief and rehabilitation plans, which can be effectively used during a damaging earthquake.
- Awareness campaign needs to be launched to educate the people about the earthquake. Prevention and mitigation begins with the dissemination of information. Moreover, Public information and community participation is key to the success of the implementation of mitigation programmes. Earthquake related curricula need to be introduced in the school stage of education inself (Tiwari, 2000). Informative and popular articles in simple languages should be written and made available to the common man. Audio-visual programmes, preferably in the local languages, have to be prepared for public use. Voluntary organizations and students may be entrusted with this job (Bapat, 1996).
- Legal measures have to be adopted to prevent earthquake disaster.
- Ordinances/Acts need to be passed to this effort as has been done in Japan and California. These shall incorporate provisions for protection of life and

property, formulation of earthquake prevention plans, establishment of quake disaster control headquarters and implementation of action plan.

- Special insurance schemes need to be initiated to cover the risk of life and property due to earthquake. This would provide a big relief to the victims of earthquakes who at present depend on the meager assistance received from CM/PM relief funds.
- Rescue team and volunteer groups have to be former in advance. NGOs, social organizations and students may be assigned this job.
- Funding mechanism for reconstruction and rehabilitation programmes should be evolved before hand.
- Rehearsal of the pre- earthquake measures needs to be carried out so that it can be effectively implemented in the hour of need.

6.2.2 During an earthquake

- The action plan prepared during pre-earthquake period has to be implemented immediately after the occurrence of an earthquake.
- The volunteer groups/rescue/search teams have to be activated to carry out the relief work.
- The affected people need to be evacuated to the safer places.
- The communication and other essential services like water supply, electricity, transport, etc. ought to be restored on emergency basis.
- Supply of food items and essentials need to be taken up. Fastest means of communication (preferably helicopter) should be used to reach the remote villages.
- Overall vigilance need to be maintained after the main shock as it is usually followed by many aftershocks. The public has to be informed about the developments on an hourly basis.

6.2.3 Post Earthquake Mitigation Measures

- Damaged structures need to be reconstructed on war tooting.
- The affected people ought to be rehabilitated.
- A comprehensive list of the safe and unsafe structures has to be made incorporating the details about their designing and method of construction.
- Loss of life and property need to be documented and published.
- Counseling need to be done to removes the fear psychosis.
- An in-depth evaluation of pre-earthquake measures needs to be done. Shortcomings, if any, need to be removed and plan, if required, may be modified.

7. References

Arya A S., FNA, FNAE "*Government of India Initiatives in Earthquake Risk Management*" Deptt. of Earthquake Engg., I.I.T. Roorkee.

Arya A S., FNA, FNAE "*Basic Concepts in Indian Standard Earthquake Resistant Design Codes*" Deptt. of Earthquake Engg., I.I.T. Roorkee.

Arya A.S. (2000), "*Engineers role in Earthquake Risk Reduction In India*" Seismic Advisor, Gujarat State Disaster Management Authority.

Arya A.S. "*Damage Risk Scenarios under Hypothetical Earthquakes of M 6.6 in Uttaranchal*" Engeering Department, University of Roorkee.

Arya A.S. (2000) "*Recent Developments Towards Earthquake Risk Reduction In India*" Special Section, Seismology.

Arya A.S. (2000), "*12th World Conference on Earthquake Engineering*" Auckland, Paper No. 2824.

ATC/SEAOC Joint Venture Training Curriculum. "*Building Safety and Earthquakes, Part A: Building Shaking and Earthquake Response*" California.

Banerjee Anuradha, Reddy K. N. and Paul p. (2002). "*Application of Remote Sensing and GIS in Demographic and Socio-Economic Analysis of Dehradun City*" Indian Cartographer.

Bianchin A. and Bravin L. "*Defining and Detecting Changes in Urban Areas*" GEDDeS Laboratory, DP, University IUAV of Venice, Italy.
alberta@iuav.it , lbravin@iuav.it

Chang Stephanie E., Rose Adam, Shinozuka Masanobu, Svekla Walter D. and Tierney Kathleen J. "*Modeling Earthquake Impact on Urban Lifeline Systems : Advances and Integration*" National Science Foundation, Earthquake Engineering Research Centers Program.

Dalaibaatar Enkhjagal, Hofstee Paul and Genderen john L. (2001)."*Assessing Seismic Risk of Ulaan Baatar by Aerospace Methods*" 22nd Asian Conference on Remote Sensing, Singapore, 5 – 9 November.
enkhee_jal@yahoo.com

Dasmohapatra Dillip, (2005). "*Seismic Hazard Assessment and Site Response Study for Seismic Microzonation of Dehradun*" Indian Institute of Remote Sensing, National Remote Sensing Agency (NRSA), Department of Space, Dehradun, India.

Davidson Rachel "*Understanding Urban Seismic Risk Around the World*" Dept. of Civil Engineering, Charlotte.
radavids@uncc.edu

Erdik Mustafa "*Earthquake Vulnerability of Buildings and a Mitigation Strategy: Case of Istanbul"*

Edrik M. and Aydmoglu N. (1998), "*Earthquake Vulnerability of Buildings in Turkey*" Istanbul, Turkey.
http://idrm03.dpri.kyoto-u.ac.jp/Paperpdf/23erdik.pdf

Erdika M., Rashidovb T., Safakc E. and Turdukulov A., (2005) "*Assessment of Seismic Risk in Tashkent, Uzbekistan and Bishkek, Kyrgyz Republic*" Department of Earthquake Engineering, Kandilli Observatory and Earthquake Research Institute, Bogazici University, Cengelkoy, Turkey.
www.elsevier.com/locate/soildyn

Gulati Brijesh, (2006). "*Earthquake Risk Assessment of Buildings: Applicability of HAZUS in Dehradun, India*" Indian Institute of Remote Sensing, National Remote Sensing Agency (NRSA), Department of Space, Dehradun, India.

Gulhan Demet and Inci Guney Ozyoriic "*The Behaviour of Traditionsl Building Systems Against Earthquake and its Comparision to Reinforced Concrete Frame Systems; Experiences of Marmara Earthquake Damage Assessment Studies In Kocaeli and Sakarya*" Ministry of Public Works and Settlement, Bank of Provinces.

Gupta K. (2001), "*The Great Gujarat Earthquake 2001 – Lessons Learnt*" 22nd Asian Conference on Remote Sensing, Nov.2001.

Gupta K. (2003), "*Use of High Resolution Sattellite Data for Detailed Urban Landuse Mapping and Urban Population Enumeration at Micro Level*" RRSSC, Dehradun and SAC Ahmedabad.

Guragain Jeewan (2004). "*GIS for Seismic Building Loss Estimation : A Case Study from Lalitpur Sub-Metropolitan City Area, Kathmandu, Nepal*" International Institute for Geo-information Science and Earth Observation (ITC), The Netherlands.

I.M.D. (2004), "*List of Some Significant Earthquakes in India and its Neighborhood*". Indian Meteorological Department, Delhi

Katayama Ritsu, Shozi Masato and Tokiya Yoshihide "*A Research on the Urban Disaster Prevention Plan Concerning Earthquake Risk Forecast by Remote Sensing in the Tokyo Bay Area*" Department of Architecture, Chiba Institute of Technology, Japan.

Khatsu Petevilie (2005). "*Urban Multi-Hazard Risk Analysis Using GIS and Remote Sensing : A Case Study of landslide, earthquake and fire hazard in a Part of Kohima Town, India*" Indian Institute of Remote Sensing, National Remote Sensing Agency (NRSA), Department of Space, Dehradun, India.

Kracke Dieter W. and Heinrich.Roswitha (2004). "*Local Seismic Hazard Assessment in Areas of Weak to Moderate Seismicity - Case Study from Eastern Germany*" Institute for Geowissenschaften, Germany.
www.elsevier.com/locate/tecto

Marfai Muh Aris and Jacob Njagih Kamwaria. "*Vulnerability Analyses and Risk Assessment for Seismic and Flood Hazard in Turialba City, Costa Rica*" International Institute for Geo-information Sciences and Earth Observation (ITC) The Netherlands.

Musson R. M. W. "*Intensity-Based Seismic Risk Assessment*" British Geological Survey. U.K.
www.elsevier.com/locate/soildyn

Nichols John M., (2005). "*A Major Urban Earthquake: Planning for Armageddon*" Department of Construction Science, College of Architecture, Texas A&M University, U.S.A.
www.elsevier.com/locate/landurbplan

Rangwala S.C. (2002) "*Town Planning*" Charotar Publishing House, Anand.
www.cphbooks.com

Ranjan Rajiv, (2005). "*Seismic Response Analysis of Dehradun City, India*" Indian Institute of Remote Sensing, National Remote Sensing Agency (NRSA), Department of Space, Dehradun, India.

"*Risk Assessment Tools for Diagnosis of Urban Areas Against Seismic Disaster (RADIUS)*" Geo-Hazard International.

http://www.geohaz.org/radius.html

Singh Pratima, (2005). "*Population Vulnerability for Earthquake Loss Estimation using*

Community Based Approach with GIS" Indian Institute of Remote Sensing, National Remote Sensing Agency (NRSA), Department of Space, Dehradun, India.

Sokhi B.S. and Maithani S. (2001), "*Developing Social Infrastructure Indicators for Dehradun Municipal Area*" Vol. No. 12, pp 23-25.
GIS@development

Taubenböck H., Kemper T. and Roth A., Voigt S. "*Assessing Vulnerability in Istanbul – An Example to Support Disaster Management with Remote Sensing at DLR-ZKI*." Center for Satellite based Crisis Information (ZKI) of the German Remote Sensing Data Center (DFD), German Aerospace Center (DLR), Germany.
hannes.taubenboeck@dlr.de, thomas.kemper@dlr.de, www.zki.caf.dlr.de

UNDP. (2004). "*Earthquake vulnerability assessment and preparedness*" New York.

USGS (2004),"*USGS Earthquake Hazardous Program: Earthquake Facts and Statistics*"
http://neic.usgs.gov/neis/eqlists/eqstats.html

Verma Narender "*Application of Remote Sensing and GIS in Earthquake Study- A Case Study of Bhuj Earthquake 2001*" Department of Geography, CSSH, M.L.Sukhadia University, Udaipur, India.
naren_verma20022002@yahoo.com

Villacis Carlos and Cardona Cynthia, Rajib K. Shaw, Pierre Mouroux, Fugen Selvitopu and Muzaffer Tuncag (1996.)."*Risk Assessment Tools for Diagnosis of Urban Areas Against Seismic Disasters*" The Secretariat of the International Decade for Natural Disaster Reduction,

Villacis Carlos A. and Cardona Cynthia N.. (1999). "*Guidelines for Implementation of Earthquake Risk Management Project*" Geohazards International, California.

Westen C.J.V. (1999), "*Application of RADIUS Method for Earthquake Loss Estimation: Kathmandu, Nepal*" ITC, Netherlands.

Westen C. J. van and Hofstee P. "*The Role of Remote Sensing and GIS in Risk Mapping and Damage Assessment for Disasters in Urban Areas*" International Institute for Aerospace Survey and Earth Sciences (ITC)

Westen Cees van and Slob Siefko (2005). "*Earthquake Hazard and Risk Assessment*" Course AIT, International Institute for Geo-information Science and Earth Observation (ITC), The Netherlands. 17 –21 October.

Williams G.R.C. (1874), "*Historical and Statistical Memoir of Dehradun*" Reprinted by Natraj Publications, Dehradun, 1985.

Yodmani Suvit, (2001) "*Disaster Risk Management and Vulnerability Reduction: Protecting the Poor*" Social Protection Workshop 6: Protecting Communities—Social Funds and Disaster Management, Asia and Pacific Forum on Poverty, Asian Development Bank, Manila,

Annexure

Questionnaire for Field Survey

SURVEY TYPE	INSTITUTE	HOUSE NO.
Educational	IIRS, Dehradun	

1. Name of the person:
2. Number of members:

AGE								
GENDER								
OCCUPATION								

3. Owner/Tenant:
4. Building Use:
   - Residential
   - Commercial
   - Other
5. Building age:
6. Building condition:
7. No. of storeys:
8. Building Type:
9. Roof material:
10. Proximity:
11. Population during day:
12. Population during night:
13. Road width in front of house:
14. Assets:

4 WHEELER	2 WHEELER	CYCLE	TV	FRIDGE	WASHING MACHINE	AC/ COOLER	COMPUTER

Pictures of the Study Area

Pic 1. Residential cum Commercial Building

Pic 2. New Building being constructed

Pic 3. Open Space (Vacant Plot)

Pic 4. Open Space (Playground)

Pic 5. Religious Building

Pic 6. Proximity between Buildings is very less

Pic 7. Narrow winding roads

Pic 8. Newly constructed building

Pic 10. Maintenance of Building is poor

Pic 9. Framed Building with RCC roof material

Pic 11. Load Bearing Structure with RBC roof material

Thank You.