DAMAGE SCENARIO UNDER GREAT EARTHQUAKES, A CASE STUDY OF 1934 BIHAR-NEPAL EARTHQUAKE

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree
of
MASTER OF TECHNOLOGY
in
DISASTER MITIGATION AND MANAGEMENT

By
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CANDIDATE'S DECLARATION

I hereby declare that the work carried out in this dissertation report entitled, "**Damage Scenario under Great Earthquakes, A Case Study of 1934 Bihar-Nepal Earthquake**", is presented on behalf of partial fulfilment of the requirements for the award of degree of "**Master of Technology**" in **Disaster Mitigation and Management** submitted to the Centre of Excellence In Disaster Mitigation And Management(CoEDMM), Indian Institute of Technology, Roorkee, under the supervision of **Dr. Mukat Lal Sharma,** Professor and Head, Department of Earthquake Engineering, Indian Institute of Technology Roorkee.

I have not submitted the record embodied in this report for the award of any other degree or diploma.

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May God bless them all!

Date: May 2015

Shivani Chouhan

ABSTRACT

Disaster situations are rapidly increasing due to population growth, urbanization, destruction of natural environment, climatic changes etc. Bihar is one of the multi-hazard prone states of India. During the past 180 years, Bihar has faced devastating earthquakes in 1833, 1934, followed by a less damaging earthquake in 1988 and very latest the 25th, 26th April 2015 Earthquake. Among all 1934 Bihar Nepal Earthquake was the worst.

It has been seen that whenever earthquake occurs, it occurs again and again. It is quite probable that an earthquake having the intensity similar to 1934 Bihar-Nepal earthquake may replicate again. Incidentally, Seismic Zoning Map of Bihar closely follows the intensity Iso-seismicity of 1934. Thus Intensity of 1934 earthquake will be taken as base for overall study.

Census of India 2001 & 2011 has been used for the Demographic and housing data for various districts of Bihar. These data includes Population growth, population density, Type of house existing in Bihar, wall & roofing material, vulnerability of houses etc. For the identification of vulnerable area, the Land use map of Bihar has been overlapped over the iso-seismal map of 1934 earthquake.

This study estimate the probable damages, Economic lost, loss of lives, expected injuries that may occur in various districts of Bihar, if 1934 earthquake intensity repeats in the recent years. Damage scenario under hypothetical recurrence of 1934 earthquake intensities has been estimated in the form of expected economic loss and social loss for various districts of Bihar using an open source software tool named SeisVARA (Seismic Vulnerability and Risk Assessment of Housing) in order to assess the seismic risk of housing stock.

The projected damage scenario highlights the absolute seriousness of the situation given the present building stock and demands that all new construction in Bihar, without any exception, must be earthquake resistant and the existing critical and large occupancy buildings need to be surveyed and retrofitted, if required.

The main reason observed for high loss and damages in some of the districts of Bihar are high Population Density, Zone V, close to epicentre, construction on the slump belt, Weak Houses to face the higher intensities, no proper planning, no guidelines and building codes were followed etc. The main aim of this study is to prepare Bihar to face upcoming earthquakes with minimum loss.

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Chapter 1

1. Introduction

1.1 Introduction

Disaster situations are increasing due to population growth, climatic change, and human interventions in the natural environment & natural resources and over utilization. Bihar is a multi-hazard prone state. It faces various types of natural and human induced disasters, for example, Floods, Drought, Earthquake, Fire, Cyclone (high speed winds), Heat Waves, Cold Waves, and Landslides etc. Preparedness is the only way to face this worst condition. So the Disaster Management Plan is the need for every state, district and at local level now.

During the past 180 years, Bihar has faced devastating earthquakes in 1833, 1934, followed by a less damaging earthquake in 1988 and very fresh the 25th, 26thApril 2015 Earthquake.

Earthquake is a natural hazard that can neither be prevented nor predicted. It is generated by the process going on inside the earth, resulting in the movement of tectonic plates. It has been seen that whenever earthquake occurs, it occurs again and again. It is quite probable that an earthquake having the intensity similar to 1934 Bihar-Nepal earthquake may replicate again. Given the extent of urbanization and the pattern of development in the last several decades, the repeat of 1934 earthquake in the upcoming years will be more disastrous in interpretation of the Population growth, increase in population density and vulnerable assets. [2]

The objective of the study is too carried out a detailed analysis using the base of SeisVARA, open source software prepared by Earthquake department, IIT Roorkee to find out expected social & economic loss in the given area due to Earthquake. Keeping in view the possible damage scenarios under hypothetical event with intensity similar to 1934 earthquake. This study estimate the probable damages, Economic lost, loss of lives that may occur in various districts of Bihar, if 1934 earthquake intensity repeats in the recent years.

This study also identified the vulnerable areas in Bihar by studying the demographic profile, housing profile and last but not the list the seismic profile of various districts of Bihar using 2001 & 2011 census.

Land use data for various districts of Bihar, 2011-2012 has been studied and overlapped over the Seismic Map of Bihar 1934 to find out the vulnerable area and vulnerable population engaged in various house types. Probable loss of human lives, expected injuries, expected economic loss has been computed for various districts for the year 2001, 2011 and also projected for the year 2021 using SeisVARA, taking it as a base and find out the best possible preparedness i.e. the Disaster Mitigation & Management Plan for Bihar. For computation of probable building damage in a given area, a relation has been established with building types and seismic intensities.

The projected damage scenario highlights the absolute seriousness of the situation given the present building stock and demands that all new construction in Bihar, without any exception, must be earthquake resistant and the existing critical and large occupancy buildings need to be surveyed and retrofitted, if required.

1.2 Study Area

As Bihar have faced various Great Earthquakes in the past century and still gets affected by various disasters from time to time. The lives and livelihood of millions of the people residing in Bihar gets affected by various disasters from time to time. So for the study of Damage Scenario under great earthquakes, Bihar is the pertinent site.

Bihar state is located in East India. It is a multi-disaster prone state. It is the 3rd largest by population; its population is the fastest-growing of any state. It is also located in the high seismic zone that falls on the boundary of the tectonic plate joining the Himalayan tectonic plate near the Bihar-Nepal Border. Major parts of the state are classified under in seismic zone IV and V by the Vulnerability Atlas of India, i.e. as having high earthquake vulnerability with the potential to cause very high degree of devastation. In all, 15.2% of the total area of Bihar is classified under Zone V and 63.7% of the total area of Bihar falls in Zone IV. [1]

Table 1: Seismic Zones of Districts of Bihar

ZONE	INTENSITY	NO. OF DISTRICTS	DISTRICT'S NAME
V	MSK IX or high	8	Sitamarhi, Madhubani, Darbhanga, Saharsa,
			Supan, Madhepura, Araria and Kishanganj
IV	MSK VIII	25	E.Champaran, W.Champaran, Shivhar, Chapra, Siwan,
			Gopalganj, Muzaffarpur, Vaishali, Samastipur, Begusarai
			Khagaria, Purnia, Katihar, Bhojpur, Patna, Jahanabad
			Arwal, Nalanda, Nawada, Shekhpura, Lakhisarai,
			Jamui, Munger, Bhagalpur and Banka
III	MSK VII	5	Buxar, Khaimur, Rohtar, Aurangabad, Gaya

1.3 Aim

"To study the Damage Scenario under hypothetical recurrence of 1934 Earthquake intensities in various districts of Bihar and prepare Bihar to face upcoming earthquakes with minimum loss."

1.4 Objectives

- To study the Seismic Profile, Past Earthquakes and land use pattern of the study area Bihar and highlight the issue that there can be the possibilities of various disasters to come again in Bihar i.e. there is possibilities of reoccurrence of Great 1934 Earthquake, which is the worst earthquake known till now in Bihar.
- To study the Housing profile, Demographic Profile and Seismic Profile of various districts of Bihar for the year 2001, 2011 and 2021 (projected) to better understands the growing pattern of Bihar.
- To introduce the open source software SeisVARA to find outs the expected economic loss, expected social loss for various years if 1934 Earthquake repeats.
- To identify the vulnerable area, vulnerable population and vulnerable housing for the study area so as to divert more focus on the needy sector.
- To promote the need of Disaster Management Plan, so as to prepare the area to face the upcoming disasters with lesser economic & social loss.
- To enhance the need of Disaster awareness programs, Retrofitting techniques for existing structures and adopting latest earthquake resistant techniques for new construction.

- To minimize the devastation occurred due to several Disasters, through better planning process.

1.5 Need

- With the increase in Urbanization, frequency of various disasters has also been increased, killing thousands of people every year. Thus there is immense needing for every state/town/district to get prepare to face upcoming disasters. Disaster management Plan is the need for every state now.
- Bihar is the multi hazard prone state faced various great earthquakes in the past few centuries. 1934 Bihar-Nepal Earthquake was the worst among all. There are still possibilities of reoccurrence of this earthquake in the future with same or nearby magnitude.
- Study of damage scenario gives an idea about the expected economic loss, expected social loss in various district of Bihar that itself creates the need to get prepare according.
- Through proper Mitigation & Management Planning that includes construction techniques, we can minimize the loss if the great earthquake repeats.

1.6 Limitations

- Considering the damage scenario under hypothetical recurrence of 1934 earthquake intensities for the year 2001, 2011 and 2021 (projected) will be the base for the overall study.
- For the overall study of Damage scenario, we have considered the intensities similar to intensities in 1934 for various districts of Bihar.
- The Population Data for the year 2001 and 2011 has been taken from Census of Population, GOI. Population data for 2021 has been projected using population projection methods.
- Population Projected for 2021 may various, as we have considered on single method i.e. Population Projection Method. It is only considered depending on the constant growth rate.
- The Housing Data for the year 2001 and 2011 has been taken from Census of Housing, GOI. Housing data for 2021 has been projected using projection methods

and taking the Housing data 2001 & 2011 as the base and household density for various districts individually.

- The present version of SeisVARA can give some knowledge to the user in writing input files, running SeisVARA, and reading output files in order to export and visualize the results within a GIS or other software, but it possibly contains some non-updated methodologies which may provide wrong results in some cases.
- The authors of the SeisVARA herewith explicitly stress that they are not responsible for the obtained results and their use within scientific or consultancy works.
- Matrix used in SeisVARA can be changed depending upon the real time situations, as said by authors of SeisVARA.
- There can be Variation in final results of economic loss and social loss, due to age of the building, mortar used in masonry, workmanship of construction, maintenance of the building, number of storey, storey height, type of roof (pitched roof, flat flexible, flat rigid), etc.
- Only the Residential and commercial buildings of various districts are considered in this study.
- House Type X are made up of cheap and light weighted material such as polythene, plastic, grasses etc. which are least vulnerable to earthquake, thus it does not cause much impact on economic and social loss. Thus we have not considered it during calculation of Economic loss and social loss.
- Results for economic loss and social loss given by SeisVARA can be differing from the real time results depending on many real time situations and conditions. Its results are only considered as expected economic and social loss. The result may vary.
- Damage scenario has been considered only to prepare the state for Disaster Management Plan taking it as base.
- Main focus of this study is to get prepared for future as well and divert the focus of Government of Bihar on this issue as well.

1.7 Methodology

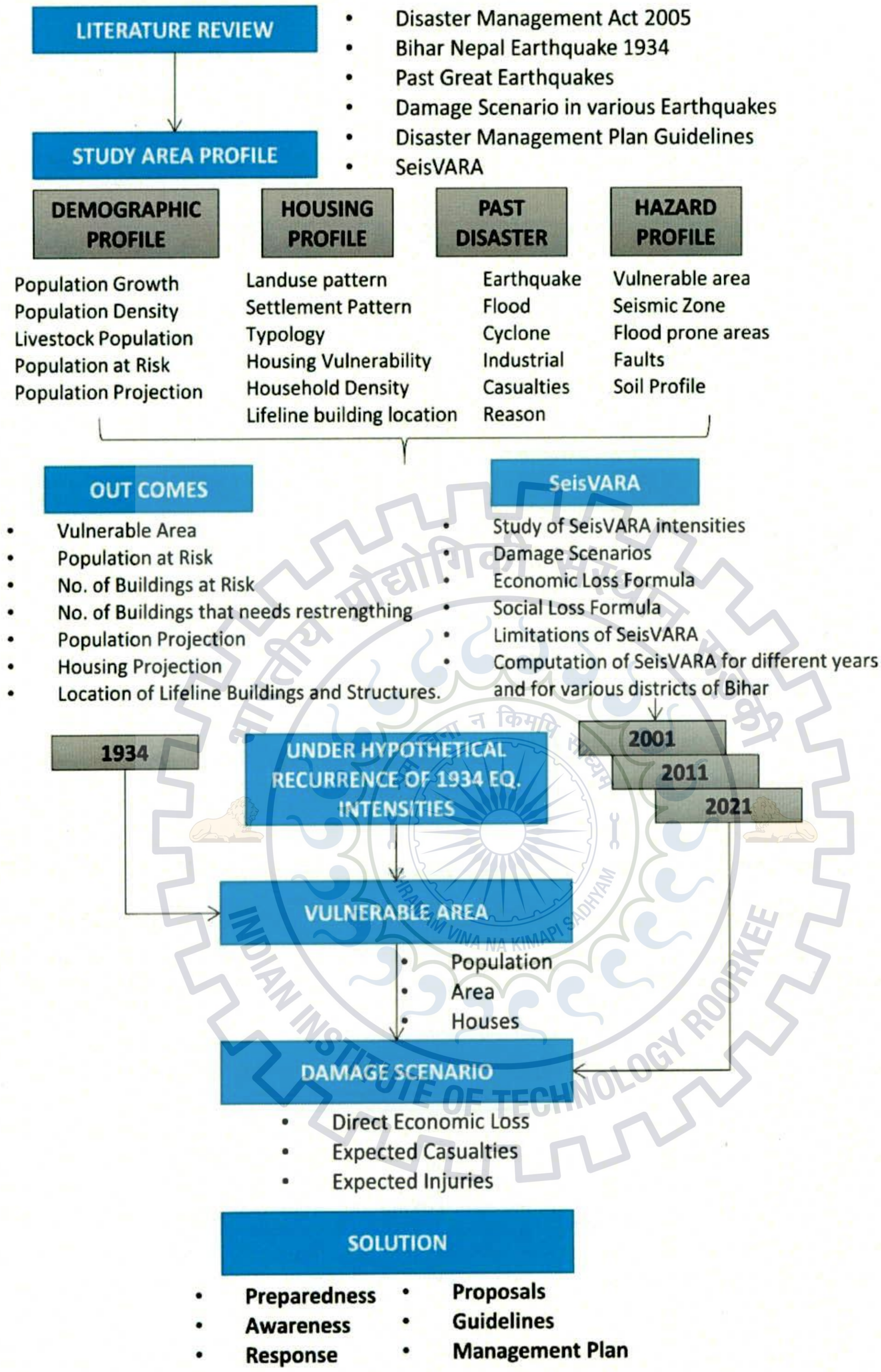
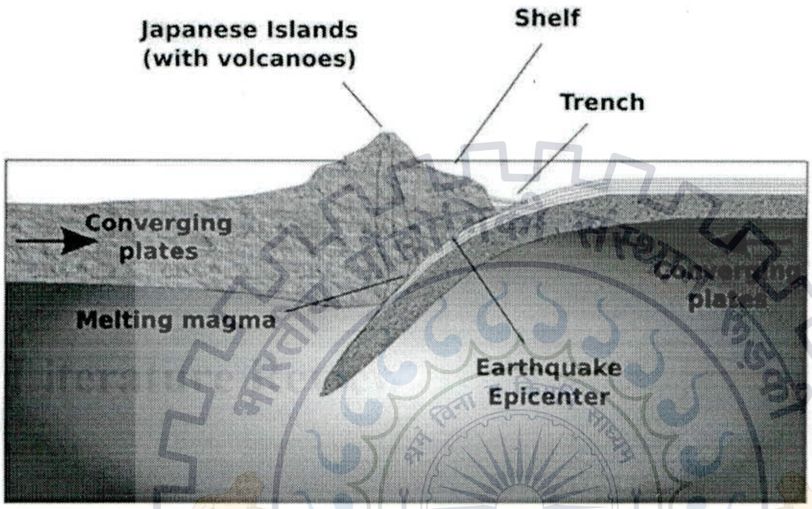


Figure 1: Methodology followed to find out damage scenario

Chapter 2

2 Literature Review

2.1 Understanding Earthquake



An earthquake is a sudden movement of the Earth, caused by the abrupt release of strain that has accumulated over a long time. For hundreds of millions of years, the forces of plate tectonics have shaped the Earth as the huge plates that form the Earth's surface slowly move over, under, and past each other. Sometimes the movement is gradual. At other times, the plates are locked together, unable to release the accumulating energy. When the accumulated energy grows strong enough, the plates break free. If the earthquake occurs in a populated area, it may cause many deaths and injuries and extensive property damage.

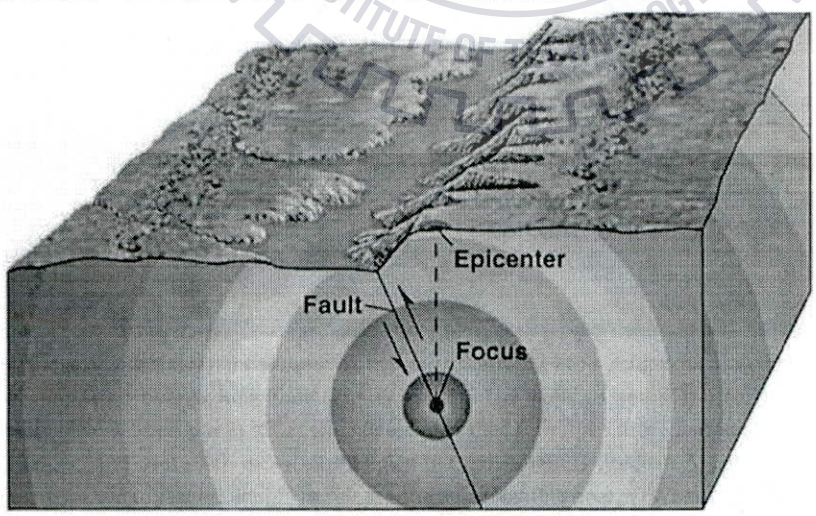


Figure 2: Understanding Earthquake

[12]

2.2 Past Earthquakes in India

Maximum Economic loss in Asia is due to Flood and Earthquake of about 359 and 314 billion respectively. Bihar is faces earthquake and flood almost every year.

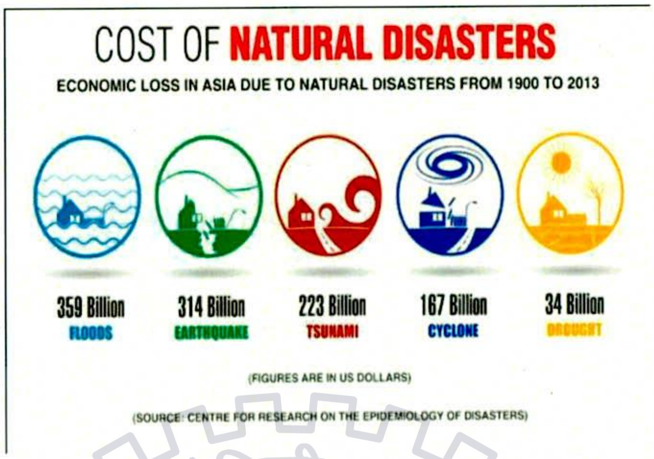


Figure 3: Economic Loss due to Natural Disasters in Asia.

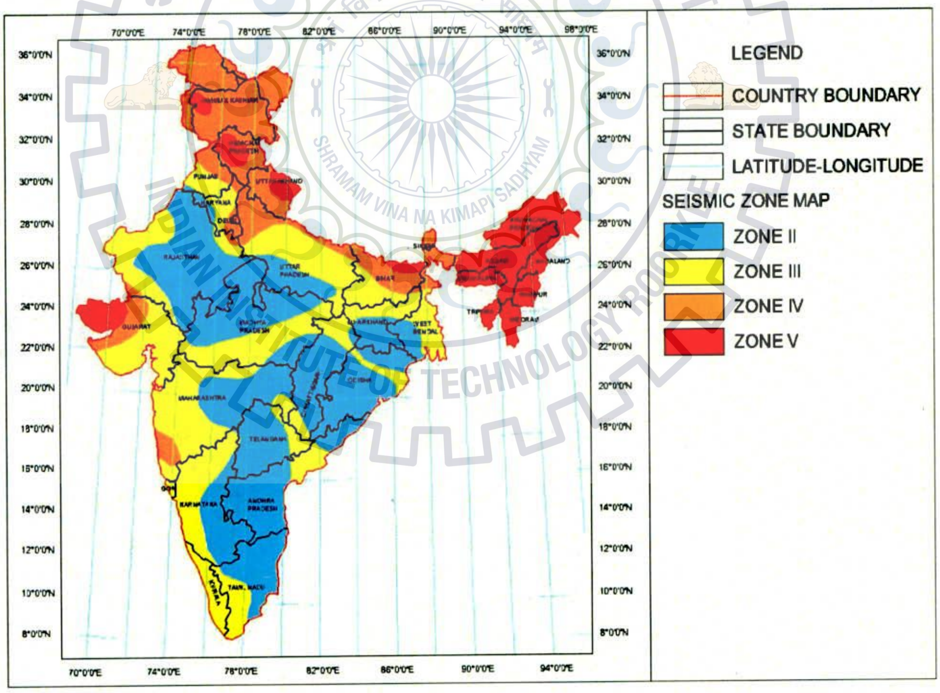


Figure 4: Seismic Zone Map of India

India is divided into four types of zones based on its vulnerability towards earthquake. More than 58.6 per cent of the landmass in India is prone to earthquakes of moderate to very high intensity;

Table 2: Earthquake Zones & Intensities

ZONE	DESCRIPTION	INTENSITY
V	Very High Risk Zone for earthquake	IX & above
IV	High Risk Zone for Earthquake	VIII
III	Moderate Risk Zone	VII
III	Low Risk Zone	VI & lower

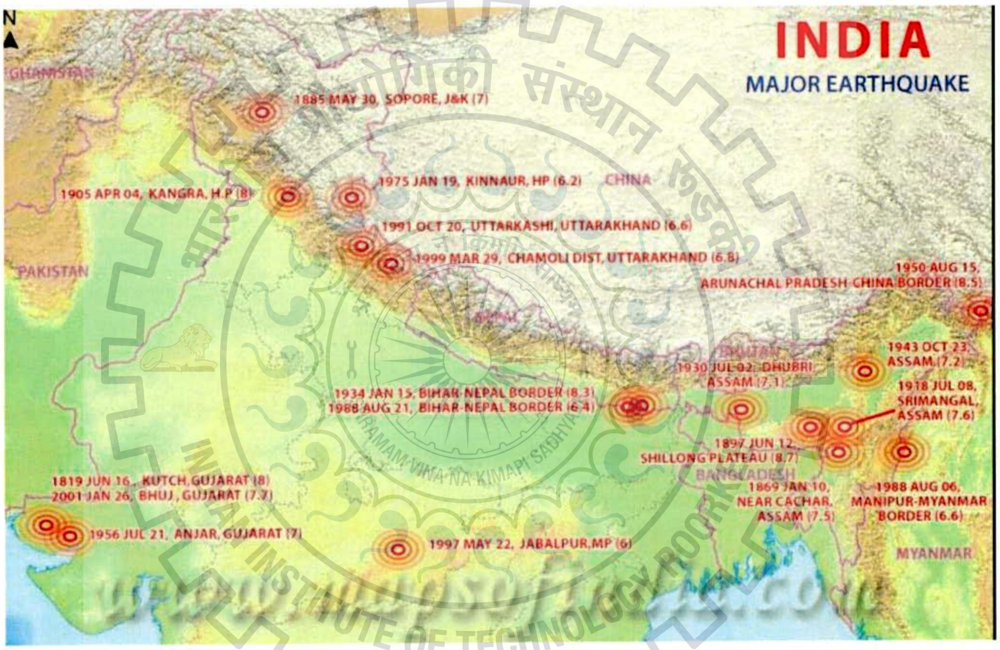


Figure 5: Showing Epicentre of Major Earthquakes in India

The Indian subcontinent has a history of devastating earthquakes of the high frequency and intensity of the earthquakes as the Indian plate is driving into Asia at a rate of approximately 47 mm/year.

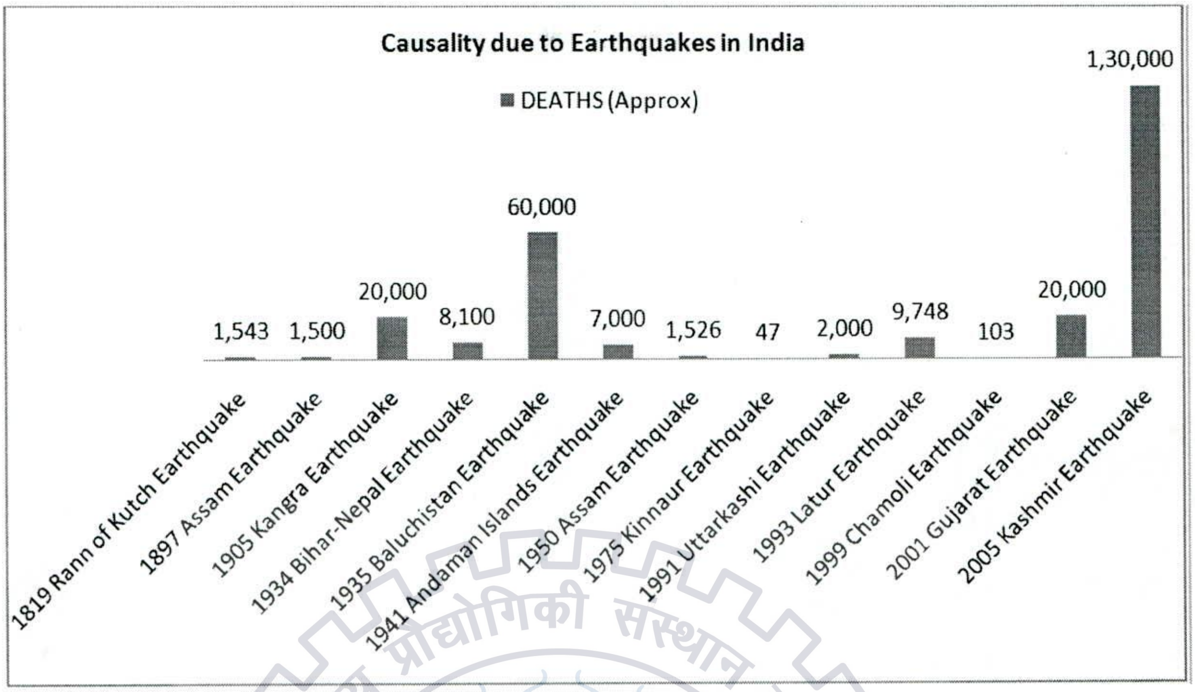


Figure 6: Casualties due to Earthquake in India in past century

2.3 Damage Scenario observed in Past Earthquakes in Bihar

2.3.1 Bihar-Nepal Earthquake 1833

Bihar-Nepal Earthquake 1833 is declared as destructive earthquake in Mallet's Earthquake Catalogue of the British Association.

Table 3: Introduction of Bihar Nepal Earthquake 1833

Year	1833
Date	26 Aug 1833
Time	Between 5.30 to 8.00 pm
Magnitude	7.5 to 8
Epicentre	Lat. 27.5 N
	Long. 86.5 E
Casualties in India	No loss
Casualties in Nepal	414

The epicentre was inside Nepal at about 100 km north from the Indian border. Extensive damage occurred in Nepal with 414 casualties. In India water was thrown out of tanks 1.2 m deep at Muzaffarpur, a Chasm of considerable size was formed in the earth at Chapra and many houses were destroyed and damaged at various districts of Bihar such as Monghyr, Rangpur, Muzaffarpur and other places. No loss of life was reported in India. [2]

2.3.2 Bihar-Nepal Earthquake 1934

Table 4: Introduction of Bihar Nepal Earthquake 1934

Year	1934
Date	15-Jan
Time	14h 13 min 25 sec IST
Magnitude	8.4 Mw
Epicentre	Lat. 26.6° N
	Long. 86.2° E
Casualties in India	8519
Casualties in Nepal	7153

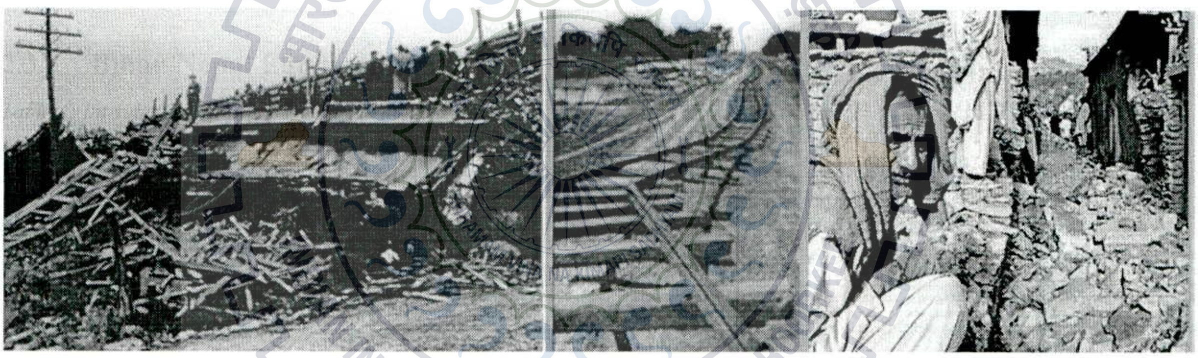


Figure 7: Damages during 1934 Earthquake in Bihar

It is one of the few most violet earthquakes experienced in India and Nepal so far wherein 7153 lives were lost in India and about 8519 in Nepal. In this earthquake the towns of Monghyr in India and Bhatgaon in Nepal were completely in ruins, so were large parts of the cities of Motihari, Muzaffarpur and Darbhanga in India and, Patna and Kathmandu in Nepal, not mentioning the numerous villages razed to the ground in both countries. Large tracts in the districts of East Champaran, Sitamarhi, Madhubani, Saharsa and Purnia in a length of about 300 km and average width of about 50 km slumped due to liquefaction of sands and at many places sand fountains and sand-boils had occurred on a large scale. In Sitamarhi, Madhubani and Purnia houses had greatly titled and sank into the ground. In Purnia 95 percent houses became uninhabitable including 50 percent destroyed. Across the Ganga River also damage in towns of Patna, Barh and Jamalpur was severe including damage to roads.

The following are the casualties reported in India (Bihar) as per Bihar State Disaster Management Authority [2]

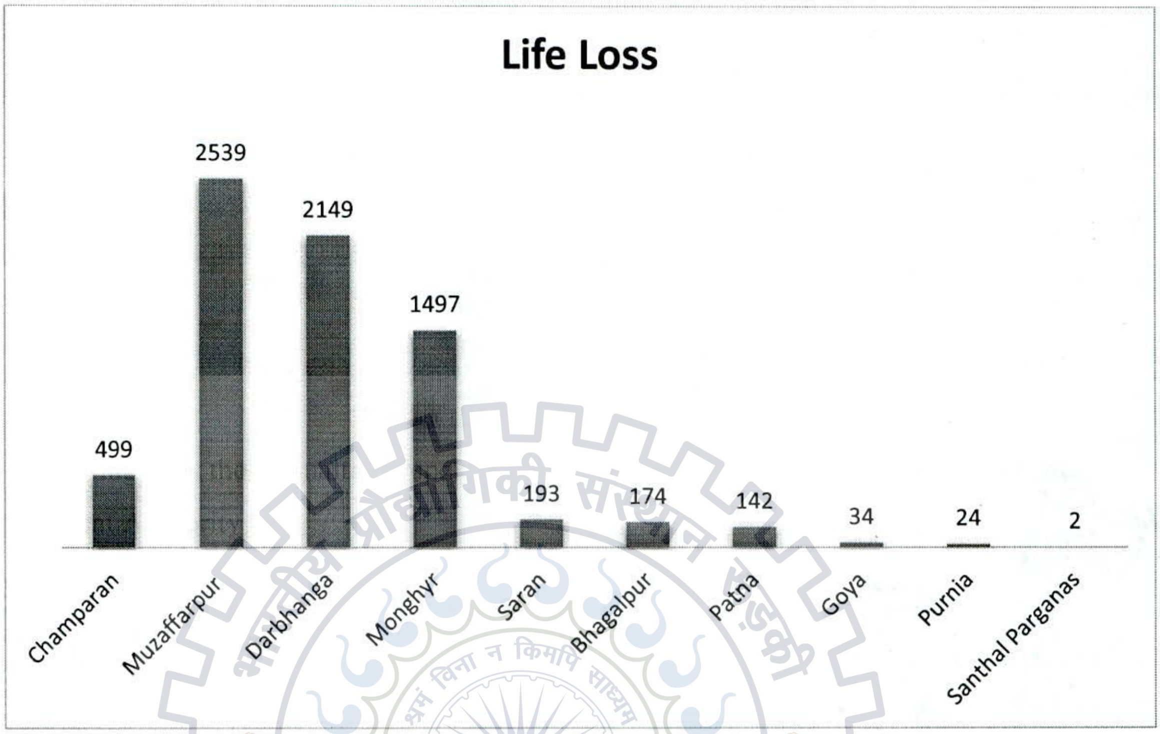


Figure 8: District-wise Casualties in Bihar in 1934

(The old districts of Muzaffarpur and Darbhanga include the present districts of Sitamarhi, Madhubani and Saharsa).

The effects of the earthquake expressed in Modified Mercalli Scale and observed in terms of the slump belt are shown in the below Fig.No.9 super imposed on the survey of India map of Bihar State published in 1974. The epicentres of the earthquakes having Magnitudes more than 5.0 are also plotted in the below figure.

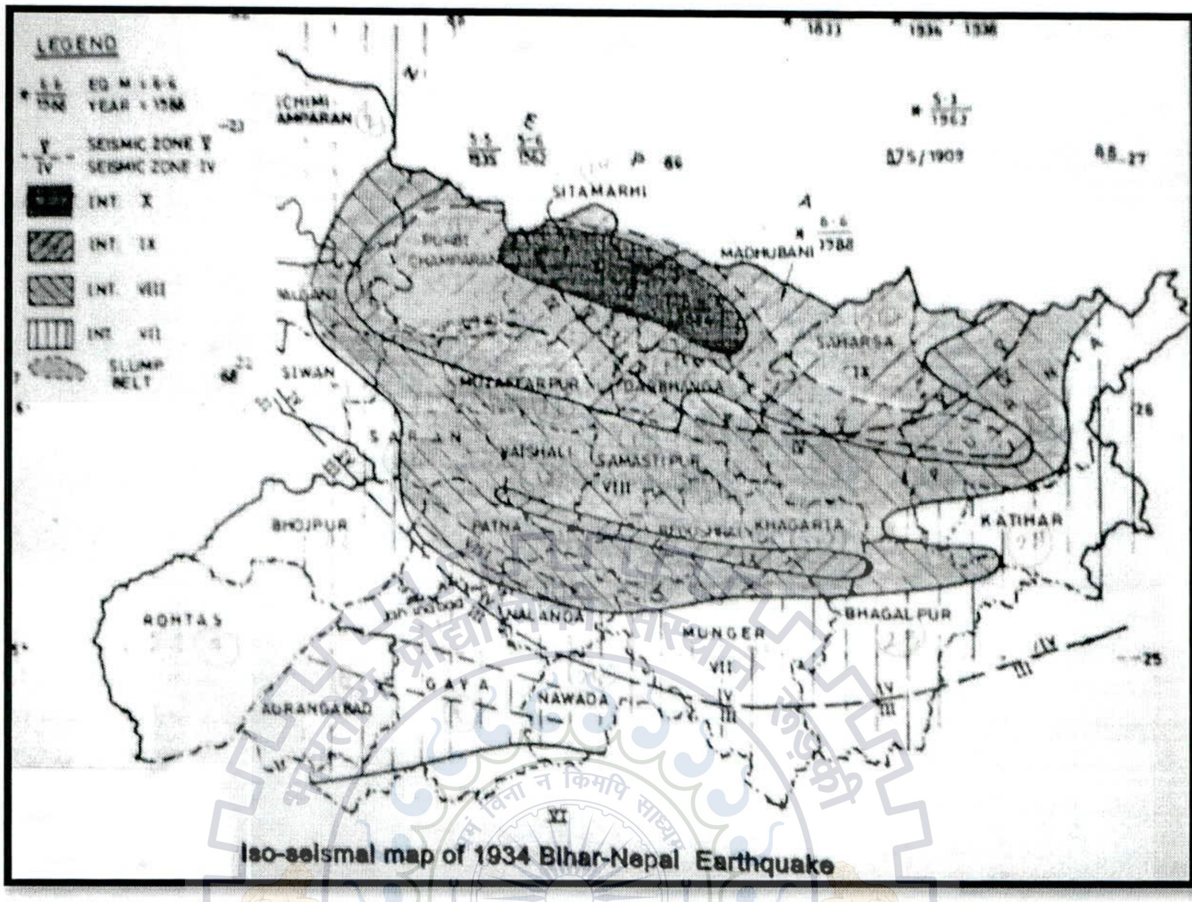


Figure 9: Iso-seismal Map of 1934 Bihar Nepal Earthquake

Refer Map 1 for more details

The seismic zones as per IS:1893-2002 are superimposed on this map to show current thinking about maximum intensity on MSK scale since seismic zone V indicates roughly areas of 'MSK IX and more' and zone IV areas of MSK VIII. Thus some of the factors that controlled the intensity distribution in this earthquake can be summarized as follows:

- Isoseismic X covered the epicentral region at the centre of the large slump belt and intensity dropped away from this area.
- Damage was seen to be severe along the river banks and low lying water logged areas near river banks (unconsolidated sandy beds). It was seen to be less on thick clay beds.
- Damage in the slump belt was due to soil sinking effects. Outside this belt collapse of buildings occurred on account of direct shock, which was more pronounced in earthen or earthen-brick composite houses and less in fired-brick houses. Also huts made from bamboo with mud plaster suffered much less damage.

- Munghyr town situated more than 120 km from the epicentre suffered much more severe damage as compared with many towns in between due to a peculiar geologic geotechnical set up. It is located on a thin shelf of alluvium abutting against Archaean quartzite. The discontinuity seems to play significant role in amplifying the ground motions greatly, due to which this town suffers damage from big as well as small earthquake motions arriving at it from any direction. [2]

2.3.3 Bihar-Nepal Earthquake 1988

Table 5: Introduction of Bihar Nepal Earthquake 1988

Year	1988
Date	21-Aug-88
Time	4h 39min 10.3 sec IST
Magnitude	6.8 M_W
Epicentre	Lat. 26 45'18"N
	Long. 86 36'57.6"E
Casualties in India	282
Casualties in Nepal	709-1450

This earthquake of M 6.6 on Richter scale according to U.S. Geological Survey occurred in India-Nepal border region at Lat 26°45'18"N, Long. 86°36'57.6"E on August 21, 1988 at 4h 39m 10.3s Indian Standard Time, that is, in the early morning hours of a day in a monsoon season when the areas in north Bihar were under floods. As a result 282 persons died and 3766 were injured in Bihar. The figures are surprisingly low in view of the fact that 149334 houses were damaged in Bihar, (Pucca private houses: collapsed 11335, major damage 19141, minor damage 34142; Kuchha houses: Collapsed 13758, major damage 27258 and minor damage 43700). Most of the damaged houses were of Unburnt or burnt brick masonry in Bihar.

Figure 10: Damages during 1988 Bihar-Nepal Earthquake

The worst affected Districts in Bihar were again Darbhanga, Madhubani and Saharsa close to the border and Munger town due to its special geologic and geotechnical set-up. The iso-seismal map of 1988 Bihar-Nepal Earthquake is shown in the below given Fig.No.10

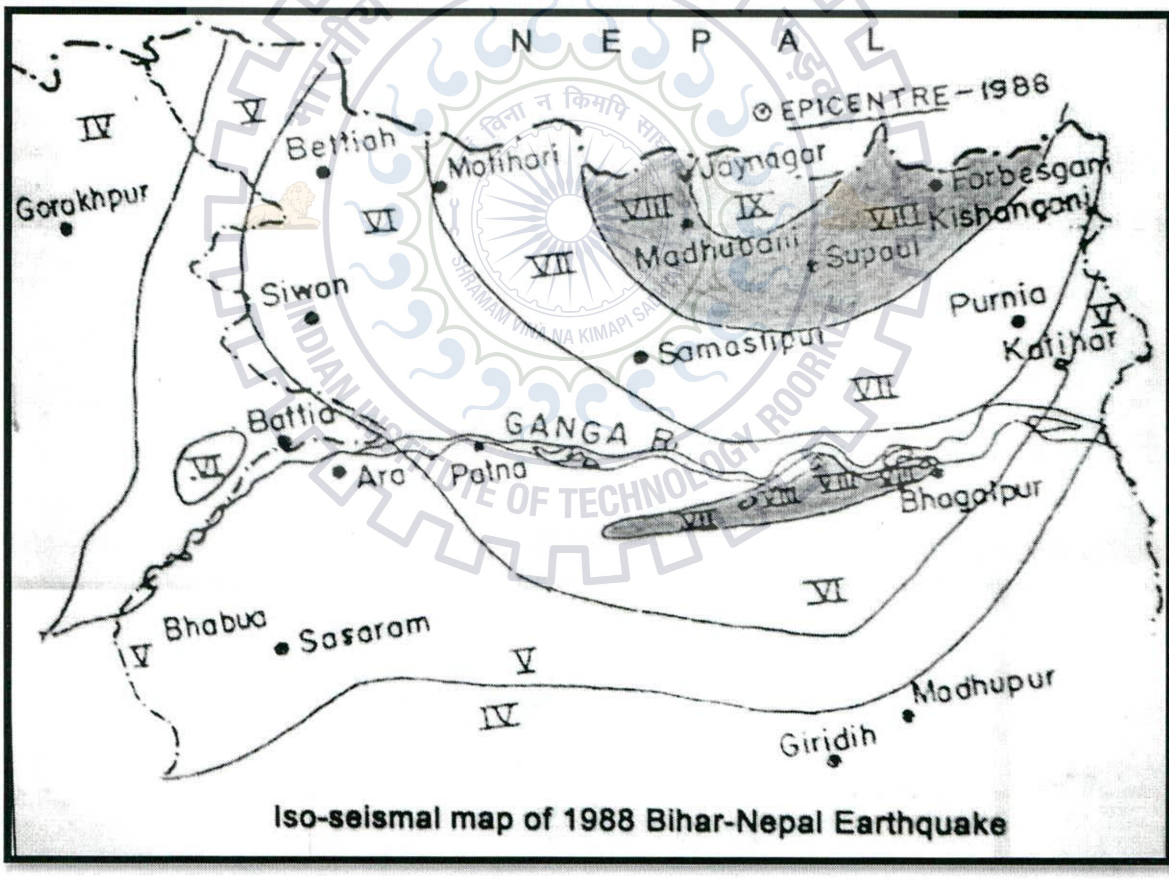


Figure 11: Iso-Seismal Map of 1988 Bihar-Nepal Earthquake

Refer Map 2 for more details

The overall damage costs in private housing and government buildings, structures and services, estimated by the various Government Departments were Rupees 108.9 crores for houses and Rs. 79.9 crores for government buildings and facilities (Rupees of year 1988).

Note: It may be mentioned that the earthquake of Magnitude 8.4 in 1934 would be about 750 times of the energy release in 6.6 earthquakes Magnitude in 1988. The repeat of 1934 in future will indeed be catastrophic in view the increased population and the vulnerable assets. [2]

2.3.4 Bihar-Nepal Earthquake 2015

Table 6: Introduction of Bihar Nepal Earthquake 2015

Year	2015
Date	25-Apr-15
Time	11.56 AM
Magnitude	7.9 Mw
Epicentre	Lat. 28.147°N
	Long. 84.708°E
Casualties in India	78*
Casualties in Nepal	6655+ confirmed deaths

Figure 12: Damage during 2015 Nepal Earthquake in Nepal

The **2015 Nepal earthquake** is the very latest earthquake that strike Nepal which had deadly damaged the Nepal with a moment magnitude (M_w) 7.9$M_s$and a maximum Mercalli Intensity of IX (*Violent*). Its epicenter was located in Nepal at Barpak, Gorkha district, and its hypocenter was at a depth of approximately 15 km (9.3 mi).

It was the worst natural disaster to strike Nepal since the 1934 Nepal–Bihar earthquake. It had so many after effects also that caused more severe damage in Nepal.

The earthquake triggered an avalanche on Mount Everest, killing at least 19,making it the deadliest day on the mountain in history.It triggered another huge avalanche in Langtang valley, where 250 were reported missing.[21]

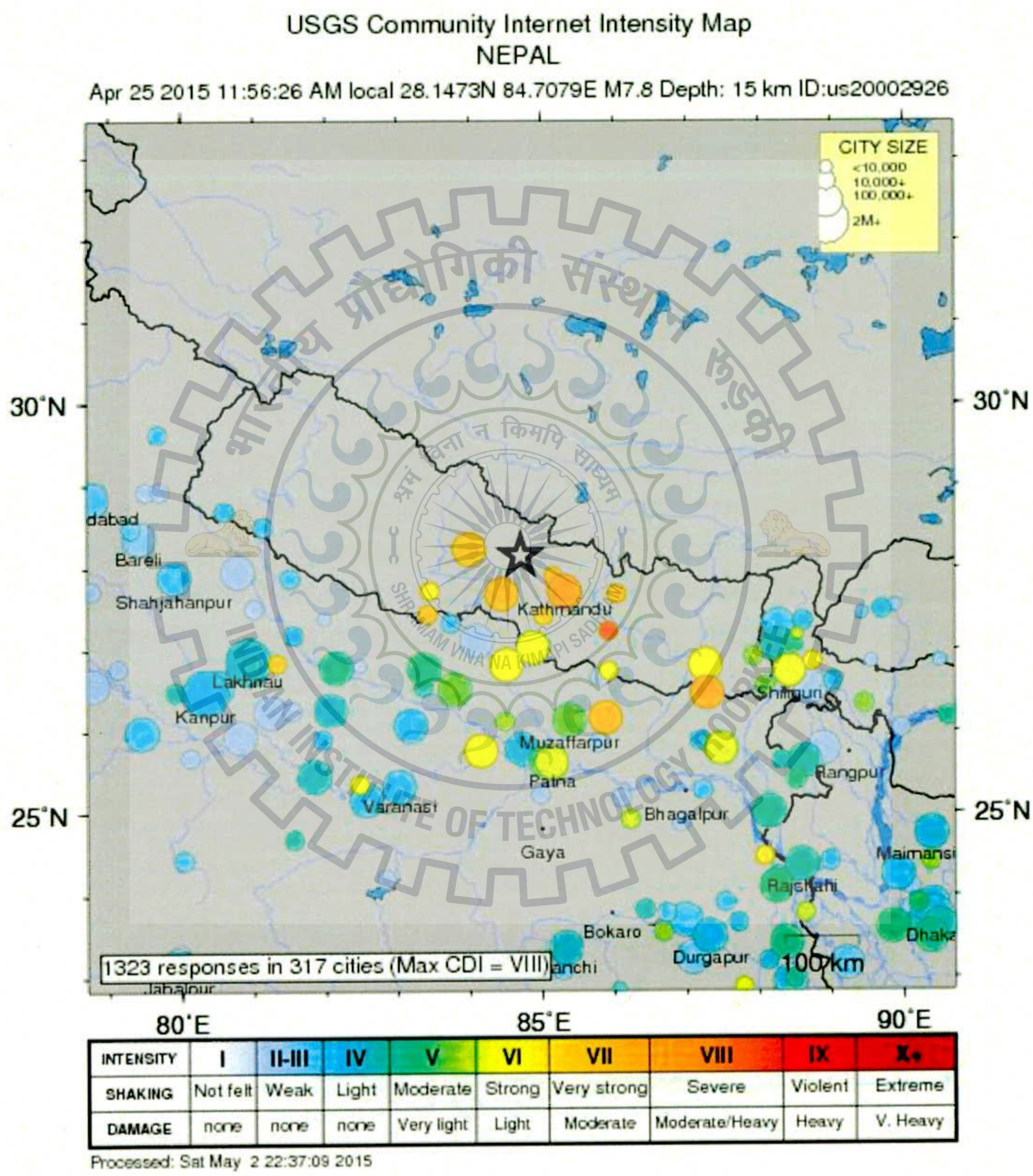


Figure 13: USGS Intensity Map of 2015 Nepal Earthquake

[13]

2.4 Comparison

Table 7: Comparison of various Earthquakes of Bihar

	The Bihar-Nepal Earthquake			
Year	**1833**	**1934**	**1988**	**2015**
Date	26 Aug 1833	15-Jan-34	21-Aug-88	25-Apr-15
Time	Between 5.30 to 8.00 pm	14h 13 min 25 sec IST	4h 39min 10.3 sec IST	11.56 AM
Magnitude	7.5 to 8	8.1 Mw	6.8 M_W	7.9 Mw
Epicentre	Lat. 27.5 N	Lat. 26.6 N	Lat. 26 45'18"N	Lat. 28.147°N
	Long. 86.5 E	Long. 86.2 E	Long. 86 36'57.6"E	Long. 84.708°E
Casualties in India	No loss	8519	282	78*
Casualties in Nepal	414	7153	709-1450	6655+ confirmed deaths

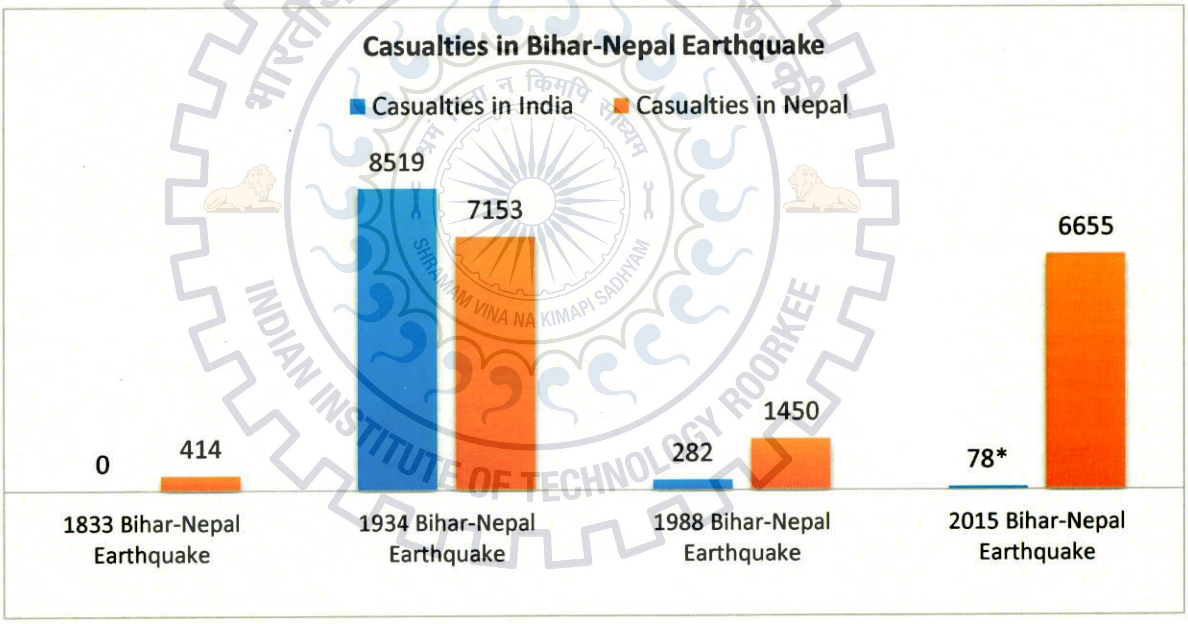


Figure 14: Casualties in various Bihar-Nepal Earthquakes

*No. of confirmed Casualties as per data provided by Indian Home Minister Rajnath Singhon27th April'2015.

Bihar-Nepal 1934 earthquake had serious impact on the population of Bihar as it was the worst earthquake till now in India. Incidentally, It has been observed that the seismic zoning map of Bihar closely follows the intensity Iso-seismals of earthquake of 1934.

2.5 Disaster Management Plan

As per National Disaster Management Authority (NDMA):

"DM Plan is a systematic, comprehensive and holistic approach towards all disasters that includes Natural as well Manmade Disasters, in order to develop an effective plan of action that would encompass disasters of all origins and shades."

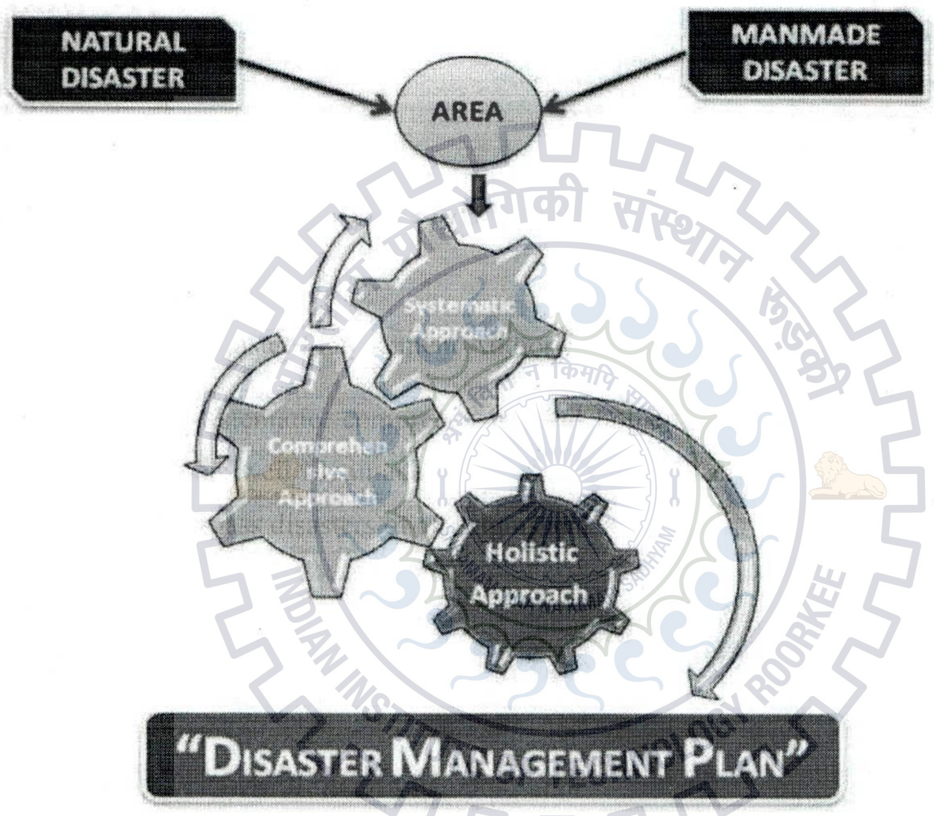


Figure 15: Disaster Management Plan Description

Chapter 3

3 SeisVARA-Intensity

3.1 Introduction to SeisVARA-Intensity

SeisVARA is Seismic Vulnerability and Risk Assessment of Housing using Intensity. It is an open-source software tool in order to assess the seismic risk of housing stock in any geographical unit.

The schematic outline of the SeisVARA has been explained in the figure below. As it is shown, the SeisVARA consists of the main risk engine (processor) and four program modules. The details of these modules are provided in the following Sections.

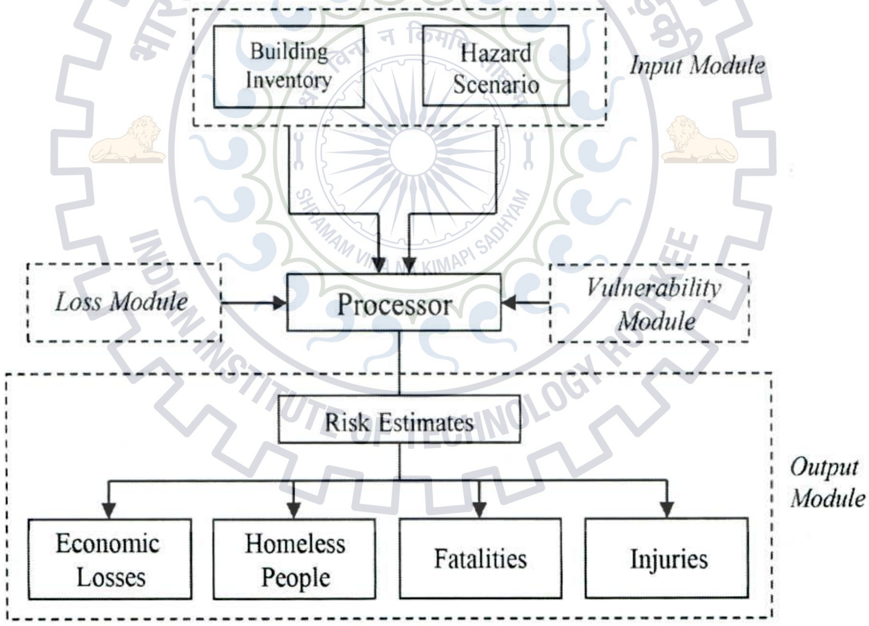


Figure 16: SeisVARA Module

Visit the following website for using, understanding and installing SeisVARAhttp://www.eqrisk.info/seis.php

3.2 Input Module

The input module has the information about the building inventory and the hazard scenario.

3.2.1 Input Data for Hazard Scenario

SeisVARA-Intensity considers seismic hazard as:

- MSK intensity value
- Method of risk estimation
  - Lower Bound Estimates
  - Upper Bound Estimates

3.2.2 Input Data for Building Inventory

Currently, SeisVARA-Intensity classifies the building inventory as:

- four different Occupancy Classes
  - residential,
  - low commercial,
  - medium
  - commercial
- high commercial) as well as
- 34 MBTs under each occupancy class (Prasad et al., 2009) as given in *table 6.*

The user has to enter the following data regarding:

- The number of Occupancy Classes
- MBTs
- The floor area
- structural and non-structural replacement costs (per sq.m. of floor area),
- total number of persons occupying the respective building typology

3.3 Vulnerable Module

The vulnerability module consists of the definition of Damage States and the Damage Probability Matrices (DPMs) for each MBT used in the case study.

3.3.1 Damage Probability Matrix (DPMs)

SeisVARA-Intensity currently provides the DPMs given by Prasad et al. (2009) and Arya (2006) that are based upon MSK-EMS intensity scales as well as those given by Coburn and Spence (2002) based on PSI scale of intensity.

3.3.2 Definition of Damage States

The definition of Damage States is given by Coburn and Spence (2002) is considered in SeisVARA-Intensity.

Table 8: Damage State Definitions

DAMAGE STATE DEFINITIONS (Coburn and Spence, 2002)			
Damage Level	**Definition**	**For load-bearing masonry**	**For RC frame buildings**
D 0	Undamaged	No visible damage	No visible damage
D 1	Slight Damage	Hairline cracks	Infill panels damaged
D 2	Moderate Damage	Cracks up to 5-20 mm	Cracks smaller than 10 mm in structure
D 3	Heavy Damage	Cracks thicker than 20 mm or wall material dislodged	Heavy damage to structural members, loss of concrete
D 4	Partial Destruction (Complete Damage)	Complete collapse of individual wall or roof support	Complete collapse of individual structural member or major deflection to frame
D 5	Collapse	More than one wall collapsed or more than half of roof	Failure of structural members to allow fall of roof or slab

3.4 Loss Module

The loss module consists of information required to estimate the direct socio-economic losses for each MBT.

3.4.1 Economic Loss

Economic loss consists of structural and non-structural loss and loss of contents. For the current version of SeisVARA, the loss model of HAZUS (FEMA, 2006) has been considered.

3.4.2 Social Loss

The Severity Definitions and Casualty Rates are taken from HAZUS (FEMA, 2006).

3.5 Output Module

The output module displays the following:

- The estimated Economic loss
- The number of homeless people in the study
- The expected life
- The expected number of injured people

The total population is simply a sum of the number of occupants provided by the user. It serves as a check on the input data.

3.6 Classification of Model Building Type (MBT)

For the classification of Module Building Types as per SeisVARA, Refer ***Annexure 1***

The classification of Module Building Types as per SeisVARA shows the different types of Model Building types, its description based on Wall types, roof types, Number of stories and its vulnerability. It has been very useful while categorizing different types of houses available in Bihar.

3.7 Characterization of Roof/Floor Type

Table 9: Characterization of Roof/Floor Type as per SeisVARA

CHARATERIZATION OF ROOF/FLOOR TYPES	
Roof/Floor Type	**Description**
R1	Light sloping roofs - corrugated asbestos cement or GI sheets on sloping rafters without cross-bracing
	Trussed roofs with light-weight sheeting (without cross-bracing)
	Trussed/hipped roofs with light-weight sheeting (with cross-bracing)
R2	Heavy sloping roofs - stones/burnt clay tiles/thatch on sloping rafters
	Heavy flat flexible roofs - wooden planks, stone/burnt clay tiles supported on wooden/steel joists with thick mud overlay
R3	Flat rigid reinforced-concrete or reinforced-masonry slabs

3.8 Formula used for Economic Lost

The total expected economic loss as per SeisVARA due to damage of building for the given occupancy class can be estimated as:

Equation 1: Expected Economic Loss Formula I, SeisVARA

$$CBD_i = \sum_{MBT=1}^{N} \left[FA_{MBT,i} \text{ x } TBA_i \text{ x } \sum_{j=1}^{5} (P(Gr_j)_{MBT} \text{ x } LR_j) \text{ x } RV_{MBT} \right]$$

where,

CBD_i = Cost of Building damage in Occupancy Class *i*

$FA_{MBT,i}$ = Percentage floor area of the respective MBT (Model Building Type) in Occupancy Class *i*

TBA_i = Total Built-up Area

$'P(Gr_j)_{MBT}$ = Probability of Damage Grade j for a given MBT

LR_j = Building Loss Ratio for Damage Grade j, including structural & non-structural damage

There can be another formula to find out expected economic loss in the given area based on the data available. For more understanding refer below equation:

Percentage floor area of the respective MBT in Occupancy Class *i* *(Let's Say for House Type A)* X Total Built up in the given area = Total Built up Area for respective MBT in Occupancy Class i (Say Type A)

$$FA_{MBT,i} \text{ x } TBA$$ *.............................equation 1*

Floor area of the respective MBT (Model Building Type) in Occupancy Class *i* *(Say for Type A)* X Total Number of Occupancy Class *i* = Total Built up Area for respective MBT in Occupancy Class i (Say Type A)

$$FA'_{MBT,i} \text{ x } TN_i$$ *.............................equation 2*

Thus, equation 1 = equation 2

$$FA_{MBT,i} \text{ x } TBA = FA'_{MBT,i} \text{ x } TN_i$$

Thus, the other Formula to find out expected Economic loss is as follows, *Equation 2: Expected Economic Loss Formula II, SeisVARA*

$$CBD_i = \sum_{MBT=1}^{N} \left[FA'_{MBT,i} \ x \ TN_i \ x \ \sum_{j=1}^{5} (P(Gr_j)_{MBT} \ x \ LR_j) \ x \ RV_{MBT} \right]$$

where,

CBD_i = Cost of Building damage in Occupancy Class *i*

$FA'_{MBT,i}$ = Floor area of the respective MBT (Model Building Type) in Occupancy Class *i*

TN_i = Total Number of Occupancy Class *i*

$P(Gr_j)_{MBT}$ = Probability of Damage Grade j for a given MBT

LR_j = Building Loss Ratio for Damage Grade j, including structural & non-structural damage

RV_{MBT} = Building Replacement Value for a given MBT

3.9 Formula used for Social Lost

Equation 3: Expected Social Loss Formula, SeisVARA

$$P(S_i)_{MBT} = \sum_{j=1}^{n} \left[(P(S_i / Gr_j) \ x \ P(Gr_j)_{MBT}) \ x \ Hd_i \ x \ TN_i \right]$$

where,

$P(S_i)_{MBT}$ = Probability of Severity Level I for a given MBT (Model Building Type)

$P(S_i / Gr_j)$ = Casualty Rate of Severity *i* for Damage Grade *j*

$P(Gr_j)_{MBT}$ = Probability of Occurrence of Damage Grade j for a given MBT

Hd_i = Household Density or No. of person per Household in Occupancy Class *i*

TN_i = Total Number of Occupancy Class *i*

3.10 Matrix to be used

3.10.1 Damage Probability Matrix

For the Damage Probability Matrix refer ***Annexure 2***

The Damage Probability Matrix was prepared based on the report by *Prasad et al., 2009 based on MSK-EMS and Arya, 2006.* It has been useful to find the lower bound damage scenario and Upper bound damage Scenario. It has the information's such as, Damage Probability of different Building Module for different intensities.

3.10.2 Loss Ratios

Table 10: Loss Ratio at different Damage States

Loss Ratio at different Damage States as per HAZUS (2006)		
GRADE	**Damage State**	**Description**
Grade 1	Slight	Damage would be a loss of 2% building's replacement cost
Grade 2	Moderate	Damage would be a loss of 10% building's replacement cost
Grade 3	Extensive	Damage would be a loss of 50% building's replacement cost
Grade 4	Complete	Damage would be a loss of 100% building's replacement cost

3.10.3 Severity Rate

Table 11: Injury Severity Level definition

Injury Severity Level definition as per HAZUS (2006)	
Severity Level	**Description**
Severity 1	Injuries requiring basic medical aid that could be administered by para professionals. These types of injuries would require bandages or observation.
Severity 2	Injuries requiring a greater degree of medical care and use of medical technology such as X-rays or surgery, but not expected to progress to a life-threatening status.
Severity 3	Injuries that pose an immediate life-threatening condition if not treated adequately and expeditiously.
Severity 4	Instantaneously killed or mortally injured.

Indoor Casualty Rates for different Damage States as per HAZUS (2006)

Table 12: Severity Rate Matrix for House Type A and B

HAZUS (HOUSE TYPE A, B)					
Casualty	Damage Grade				
Level (%)	Slight (G1)	Moderate (G2)	Extensive (G3)	No Collapse (G4)	Collapse (G5)
Severity 1	0.05	0.35	2	10	40
Severity 2	0	0.4	0.2	2	20
Severity 3	0	0.001	0.002	0.02	5
Severity 4	0	0.001	0.002	0.02	10

Table 13: Severity Rate Matrix for House Type C

HAZUS (HOUSE TYPE C)					
Casualty	Damage Grade				
Level (%)	Slight (G1)	Moderate (G2)	Extensive (G3)	No Collapse (G4)	Collapse (G5)
Severity 1	0.05	0.25	1	5	40
Severity 2	0	0.03	0.1	1	20
Severity 3	0	0	0.001	0.01	5
Severity 4	0	0	0.001	0.01	10

Table 14: Severity Rate Matrix for House Type D

HAZUS (HOUSE TYPE D)					
Casualty Level (%)	Damage Grade				
	Slight	Moderate	Extensive	No Collapse	Collapse
Severity 1	0.05	0.2	1	5	40
Severity 2	0	0.025	0.1	1	20
Severity 3	0	0	0.001	0.01	5
Severity 4	0	0	0.001	0.01	10

Table 15: Severity Rate Matrix for Type E

HAZUS (HOUSE TYPE E)					
Casualty Level (%)	Damage Grade				
	Slight (G1)	Moderate (G2)	Extensive (G3)	No Collapse (G4)	Collapse (G5)
Severity 1	0.05	0.02	1	5	40
Severity 2	0	0.025	0.1	1	20
Severity 3	0	0	0.001	0.01	5
Severity 4	0	0	0.001	0.01	10

Chapter 4

4 Terms Required to study Damage Scenario

4.1 Housing Data Required for Working out Damage Scenario

The best comprehensive data on types of housing units is being collected in the National Census exercise being conducted every 10 year in India. The data looked upon for this study is from Housing Census Data 2001 & 2011. The data in 2011 & 2011 Census classifies the various building types based on wall material and roof material which are considered most important in the damaging impacts of earthquakes, floods and cyclonic winds. In this report the impact of earthquake Intensities has only been considered.

We may consider Housing Sector comprising of all buildings as per Census 2001- the Housing Series, where buildings are classified in there different ways "rural and urban", based on "functional uses", and as "permanent semi permanent or temporary", these are defined in the *annexure 17* at the last of the report.

4.2 Walling Material Classification

The impact of various earthquake intensities on buildings is indicated in the description given in MSK intensity scales. The building types for specifying the damage are classified as A, B and C types which are defined as follows (Refer IS 1893 (Part 1) : 2002, Annex d) :-

- **Type A:** Buildings in rural structures, un-burnt brick houses, clay houses, stone, mud etc.
- **Type B:** Ordinary brick buildings, building of the large block and prefabricated type
- **Type C:** Concrete building, well built wooden structures.

It is seen that in the rural and urban areas of India, many houses are constructed by biomass type wall material such as

- Grass
- Thatch
- Bamboo
- Plastic/ Polythene
- G.I.
- Metal
- Asbestos sheets etc.

These materials do not fall under the categories A, B and C. We have therefore classifies such materials under type X. To be able to correlate the buildings types in India stipulated in 2001 & 2011 Census with the building types defined under MSK intensities, the house type tabulation was reworked as given below:

Type A1: Mud &Unburnt Brick Wall

Figure 17: Type A1 house, Mud and Un-Burnt Brick Wall

Type A2: Stone Wall

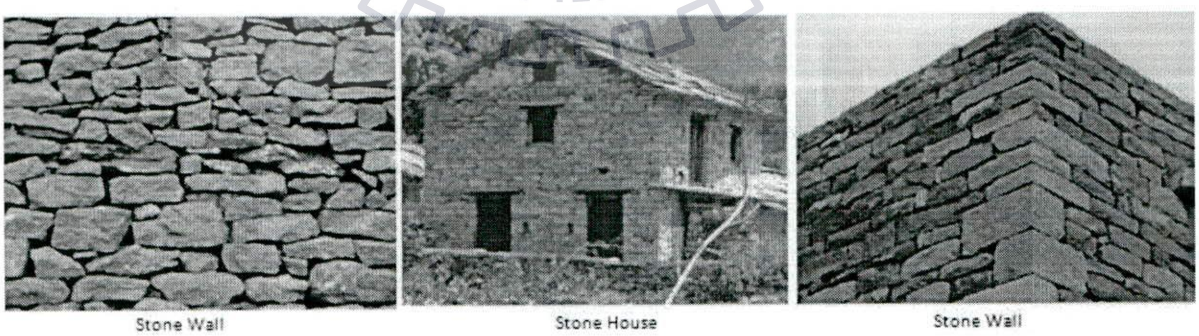


Figure 18: Type A2 houses, Stone Wall

Type B: Burnt Brick Wall

Figure 19: Type B House, Burnt Brick Wall

Type C1: Concrete Wall

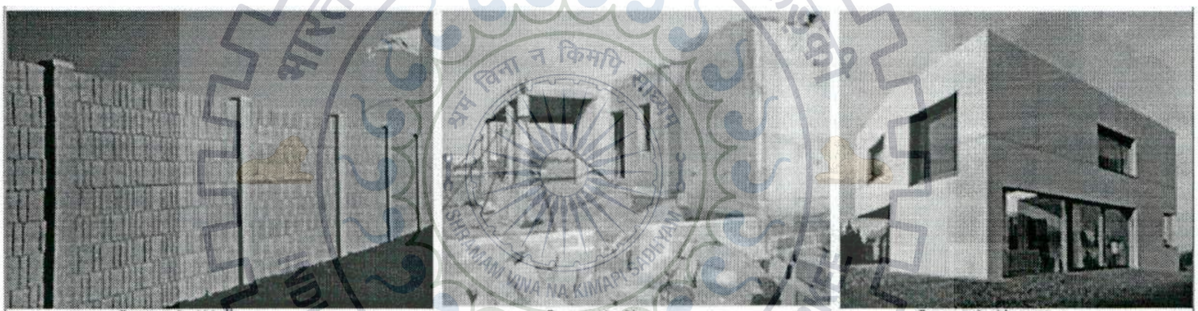


Figure 20: Type C1, Concrete Wall

Type C2: Wood Wall

Figure 21: Type C2 House, Wood Wall

Type X: Grass/ Plastic/Bamboo etc, Plastic/Polythene, G.I./Metal/ Asbestos sheets and 'any other materials'.

Figure 22: Type X House, Other Material wall

For computation of the numbers of census housing units under various damageability grades, the type C1 and C2 has been summed up and named as Type C. Type X, having low vulnerability, has not been considered for computation of damageability.

4.3 Roofing Material Classification

The roofing materials were classified under three roof types as follows:

- **Category R1:** Light weight pitched roofs consisting of grass, thatch, bamboo, wood, plastic, polythene, GI Metal, Asbestos Sheets, Other similar light materials.
- **Category R2:** Pitched roofs with heavy weight covering such as earthen tiles, slates.
- **Category R3:** Heavy flat roofs consisting of wooden joints carrying bricks and earth fill, stone slabs, RB or RC roof slabs.

4.4 Damage Grades

These are defined in MSK Intensity Scale as follows:

(Refer IS 1893 (Part 2) : 2002, Annex D) – Classification of Damage of Buildings

Table 16: Damage Grades

Grades		Damage	Description
G5	Grade 5	Total Damage	Total collapse of the buildings
G4	Grade 4	Destruction	Gaps in walls; parts of buildings may collapse; separate parts of the buildings lose their cohesion and inner wall collapse
G3	Grade 3	Heavy Damage	Large and deep cracks in walls and plaster; fall of chimneys
G2	Grade 2	Moderate Damage	Small cracks in walls and plaster; Fall of fairly large pieces of plaster; Cracks in Chimneys fall down
G1	Grade 1	Slight Damage	Fine cracks in plaster; fall of small pieces of plaster

4.5 Earthquake Damaging Intensity Scale

The **Mercalli intensity scale** is a seismic scale used for measuring the intensity of an earthquake. It measures the *effects* of an earthquake on the Earth's surface, humans, objects of nature, and man-made structures on a scale from I (not felt) to XII (total destruction). The intensity of an earthquake is not totally determined by its magnitude. It is not based on first physical principles, but is, instead, empirically based on observed effects.

More for brief about the intensities of earthquake and its effects refer ***Annexure 4***

For Probability of Damage stated in MSK intensities from VI to IX Refer **Annexure 5**

4.6 Relationship of House Types with Earthquake Damaging Intensities

Numerical values have been assigned to different damage grades for computation through a computer based on **Most**, **Many** and a **Few**.

Table 17: Relationship of House Type with Earthquake Damaging Intensities

Type of Building	Zone III	Zone III	Zone III
	Intensity: MSK VII	Intensity: MSK VIII	Intensity: MSK IX
A	10% : G4	10% : G5	50% : G5
	75% : G3	75% : G4	Rest : G4 or G3
	Rest : G2 or G1	Rest : G3 or G2	
B	10% : G3	10% : G4	10% : G5

	50% : G2	75% : G3	50% : G4
	Rest : G1	Rest : G2	Rest : G3
C	10% : G2	10% : G3	10% : G4
	50% : G1	75% : G2	50% : G3
	Rest : No damage	Rest : G1	Rest : G2
X	10% : G1	10% : G2	10% : G3
	Rest : No damage	Rest : No damage	50% : G2
			Rest : G1

Notes:

1) *% shown in the table above donates the average percentage of number of buildings of a particular type in the area under consideration.*
2) *10% shown above may range from 5% to 15%; 50% may range from 40% to 60% and 75% may range from 60% to 90%.*
3) *Variation in % are due to age of the building, mortar used in masonry, workmanship of construction, maintenance of the building, number of storey, storey height, type of roof (pitched roof, flat flexible, flat rigid), etc.*

Chapter 5

5 Study Area Profile

5.1 Introduction

Bihar is a multi-hazard prone state. It faces various types of natural and human induced disasters, for example, Floods, Drought, Earthquake, Fire, Cyclone (high speed winds), Heat Waves, Cold Waves, and Landslides etc. In addition many accidents also take place in the State. Bihar has a long history of disasters.

Table 18: General Profile of Bihar

BIHAR	
COUNTRY	INDIA
REGION	EAST INDIA
CAPITAL	PATNA
DISTRICTS	38
AREA (SQ.KM)	94163
AREA RANK	13th
POPULATION 2011	103804637
POPULATION RANK	3rd
POPULATION DENSITY	1106/SQ.KM
LITERACY	63.40%

[5]

5.2 Location

Figure 23: Location Map of Bihar

5.3 Demographic Profile

As per the census data of 2001, the Demographic profile of Bihar highlights the following:

- Bihar's total population as per census 2001 was 82,998,509 (43,243,795 male and 39,754,714 female), which makes Bihar as the third most populated state of India.
- Nearly 85% of the Bihar's population was living in rural areas.
- Almost 58% of the population of Bihar was youth population i.e. below 25 years age, which is the highest in India.
- The average population density was 881 persons per sq.km.
- The sex ratio was 919 females per 1000 males.

Table 19: Demographic Profile of various districts of Bihar, for the year 2001 and 2011

	DISTRICT	AREA (SQ.KM)	POPULATION 2001	POPULATION DENSITY 2001	POPULATION 2011	POPULATION DENSITY 2011	GROWTH RATE	SEX RATIO
1	PASHCHIM CHAMPARAN	5229	3043044	581.96	3935042	752.54	29.29	909
2	PURBA CHAMPARAN	3969	3933636	991.09	5099371	1284.80	29.43	902
3	SHEOHAR	443	514288	1160.92	656246	1481.37	27.19	893
4	SITAMARHI	2199	2669887	1214.14	3423574	1556.88	27.62	899
5	MADHUBANI	3501	3570651	1019.89	4487379	1281.74	25.51	926
6	SUPAUL	2410	1745069	724.10	2229076	924.93	28.66	929
7	ARARIA	2829	2124831	751.09	2811569	993.84	30.25	921
8	KISHANGANJ	1884	1294063	686.87	1690400	897.24	30.4	950
9	PURNIA	3228	2540788	787.11	3264619	1011.34	28.33	921
10	KATIHAR	3056	2389533	781.92	3071029	1004.92	28.35	919
11	MADHEPURA	1787	1524596	853.16	2001762	1120.18	31.12	911
12	SAHARSA	1702	1506418	885.09	1900661	1116.72	26.02	906
13	DARBHANGA	2278	3285473	1442.26	3937385	1728.44	19.47	911
14	MUZAFFARPUR	3173	3743836	1179.90	4801062	1513.10	28.14	900
15	GOPALGANJ	2033	2149343	1057.23	2562012	1260.21	19.02	1021
16	SIWAN	2219	2708840	1220.75	3330464	1500.89	22.7	988
17	SARAN	2641	3251474	1231.15	3951862	1496.35	21.64	954
18	VAISHALI	2036	2712389	1332.21	3495021	1716.61	28.57	895
19	SAMASTIPUR	2905	3413413	1175.01	4261566	1466.98	25.53	911
20	BEGUSARAI	1917	2342989	1222.22	2970541	1549.58	26.44	895
21	KHAGARIA	1486	1276677	859.14	1666886	1121.73	30.19	886
22	BHAGALPUR	2569	2430331	946.02	3037766	1182.47	25.36	880

23	BANKA	3018	1608778	533.06	2034763	674.21	26.48	907
24	MUNGER	1419	1135499	800.21	1367765	963.89	20.21	876
25	LAKHISARAI	1229	801173	651.89	1000912	814.41	24.77	902
26	SHEIKHPURA	689	525137	762.17	636342	923.57	21.29	930
27	NALANDA	2354	2368327	1006.09	2877653	1222.45	21.39	922
28	PATNA	3202	4709851	1470.91	5838465	1823.38	23.73	897
29	BHOJPUR	2473	2233415	903.12	2728407	1103.28	21.63	907
30	BUXAR	1624	1403462	864.20	1706352	1050.71	21.67	922
31	KAIMUR (BHABUA)	3363	1284575	381.97	1626384	483.61	26.17	920
32	ROHTAS	3850	2448762	636.04	2959918	768.81	20.78	918
33	JEHANABAD	1569	924839	589.44	1125313	717.22	21.68	922
34	AURANGABAD	3303	2004960	607.01	2540073	769.02	26.18	926
35	GAYA	4978	3464983	696.06	4391418	882.17	26.43	937
36	NAWADA	2492	1809425	726.09	2219146	890.51	22.63	939
37	JAMUI	3099	1397474	450.94	1760405	568.06	25.85	922
	BIHAR (TOTAL)	**94156**	**82292229**	**874.00**	**103398609**	**1098.16**	**25.41**	**918.22**

5.4 Population Projection for 2021

Arithmetic Numerical Case

Given

Population of Bihar, Source: Census of India
$T_1 = 2001$, P_1=8,22,92,229
$T_2 = 2011$, P_2=10,33,98,609

Find:

Arithmetic Growth Constant, K_a
Projected Population in 2021, P_{2021}

Formula Used

K_a = Arithmetic Growth Constant

$$\mathbf{K_a = (P_{2011} - P_{2001}) / (T_{2011} - T_{2001})}$$

where,

P_{2001} is Population in 2001
P_{2011} is Population in 2011
T_{2001} is Year 2001
T_{2011} is Year 2011

P_{2021} = Population in 2021

$$\mathbf{P_{2021} = P_{2011} + K_a (T_{2021} - T_{2011})}$$

where,

P_{2021} is Population in 2021 (Projected Population)
P_{2011} is Population in 2011
T_{2021} is Year 2021
T_{2011} is Year 2011
K_a = Arithmetic Growth Constant

Any population and the corresponding year may be used:

Solution

$\mathbf{K_a = (P_{2011} - P_{2001}) / (T_{2011} - T_{2001})}$
= (10,33,98,609 – 8,22,92,229) / (2011-2001)
= (2,11,06,380/10)
= 21,10,638

$\mathbf{P_{2021} = P_{2011} + K_a (T_{2021} - T_{2011})}$
P_{2021} = 10,33,98,609 + 21,10,638 (2021-2011),
based on 2011
P_{2021} = 10,33,98,609 + 2,11,06,380
P_{2021} = 12,45,04,989

Projected Population for the 2021 in Bihar is<u>12,45,04,989</u>

In words, Twelve Crores, Forty Five Lakh, Four Thousand, Nine hundred and Eighty Nine

*Refer **Annexure 6** for Population projected for various districts of Bihar for the year 2021.*

5.5 Population Density Comparison

Table 20: Population Density of various districts of Bihar for the year 2001, 2011 and projected for 2021

DISTRICT	POPULATION DENSITY 2001	POPULATION DENSITY 2011	PROJECTED POPULATION DENSITY 2021
PASHCHIM CHAMPARAN	581.96	752.54	923.13
PURBA CHAMPARAN	991.09	1284.8	1578.51
SHEOHAR	1160.92	1481.37	1801.81
SITAMARHI	1214.14	1556.88	1899.62
MADHUBANI	1019.89	1281.74	1543.59
SUPAUL	724.1	924.93	1125.76
ARARIA	751.09	993.84	1236.59
KISHANGANJ	686.87	897.24	1107.61
PURNIA	787.11	1011.34	1235.58
KATIHAR	781.92	1004.92	1227.92
MADHEPURA	853.16	1120.18	1387.2
SAHARSA	885.09	1116.72	1348.36
DARBHANGA	1442.26	1728.44	2014.62
MUZAFFARPUR	1179.9	1513.1	1846.29
GOPALGANJ	1057.23	1260.21	1463.2
SIWAN	1220.75	1500.89	1781.02
SARAN	1231.15	1496.35	1761.55
VAISHALI	1332.21	1716.61	2101.01
SAMASTIPUR	1175.01	1466.98	1758.94
BEGUSARAI	1222.22	1549.58	1876.94
KHAGARIA	859.14	1121.73	1384.32
BHAGALPUR	946.02	1182.47	1418.92
BANKA	533.06	674.21	815.36
MUNGER	800.21	963.89	1127.58
LAKHISARAI	651.89	814.41	976.93
SHEIKHPURA	762.17	923.57	1084.97
NALANDA	1006.09	1222.45	1438.82
PATNA	1470.91	1823.38	2175.85
BHOJPUR	903.12	1103.28	1303.44
BUXAR	864.2	1050.71	1237.22
KAIMUR (BHABUA)	381.97	483.61	585.25
ROHTAS	636.04	768.81	901.58
JEHANABAD	589.44	717.22	844.99

AURANGABAD	607.01	769.02	931.03
GAYA	696.06	882.17	1068.27
NAWADA	726.09	890.51	1054.92
JAMUI	450.94	568.06	685.17
BIHAR (TOTAL)	**868.12**	**1095.05**	**1352.81**

With the help of the colour coding in district map of Bihar for better understanding and analysis. It has been shown in the following maps the increase in population density for the year 2001, 2011 and also projected for 2021. Population Density describes the no. of persons per sq. km.

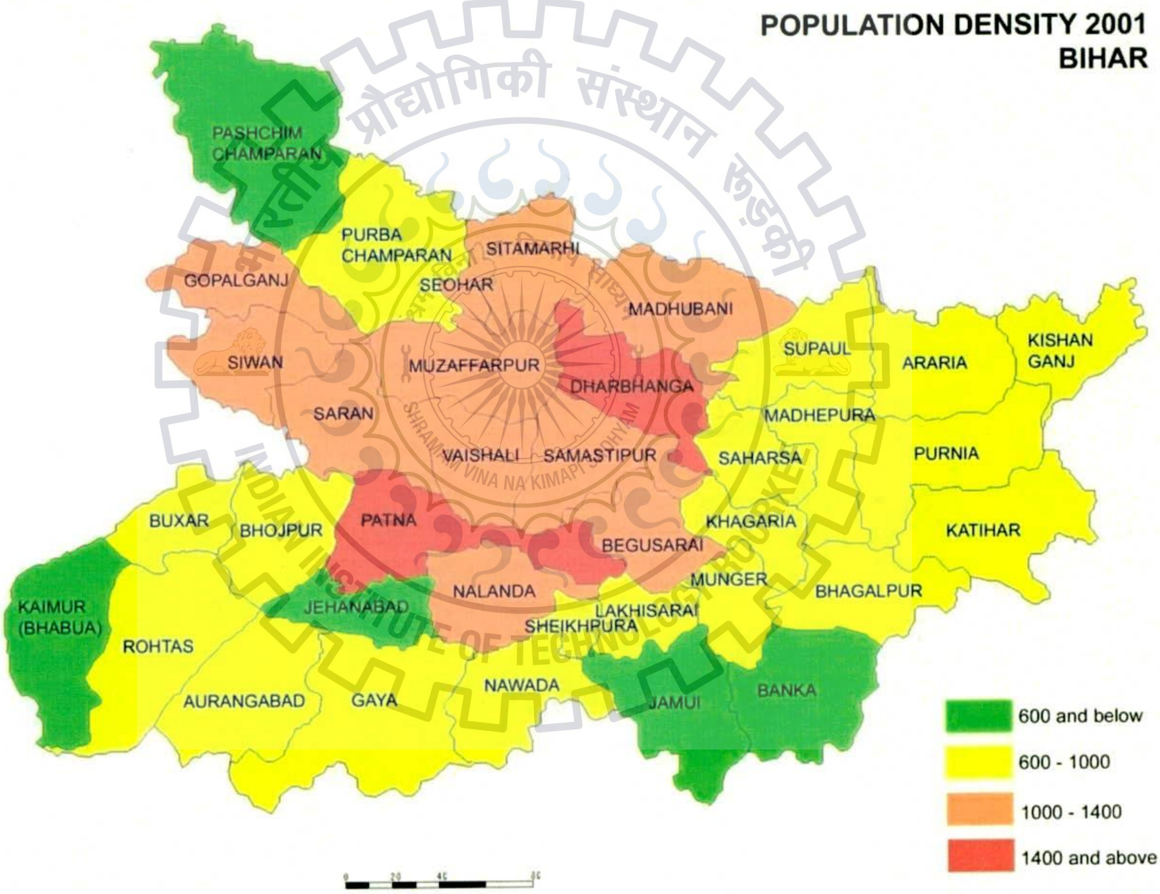


Figure 24: Population Density of Bihar, 2001

In the year 2001, Patna and Dharbhanga has the highest Population density between 1400 to 1800 persons per sq. km. while Pashchimchamparan, Kaimur, Jehanabad, Banka and Jamui have the least population density of less than 600 persons per sq. km.

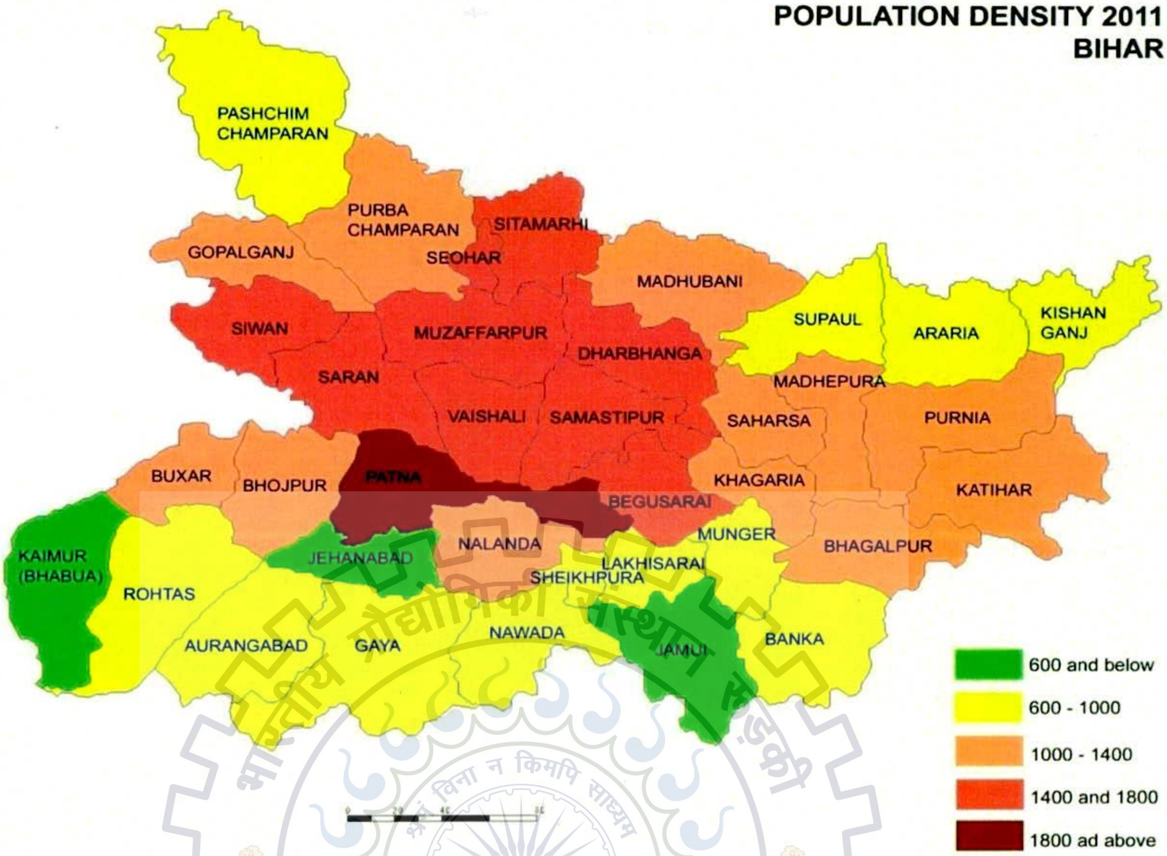


Figure 25: Population Density of Bihar, 2011

Population increasing in Bihar was so high that we have to create one new legend in this map i.e. population density of above 1800 persons per sq.km.

As per 2011 census, Patna has the highest Population density of about 1823 persons per sq. km. while Kaimur, Jehanabad and Jamui have the least population density of less than 600 persons per sq. km.

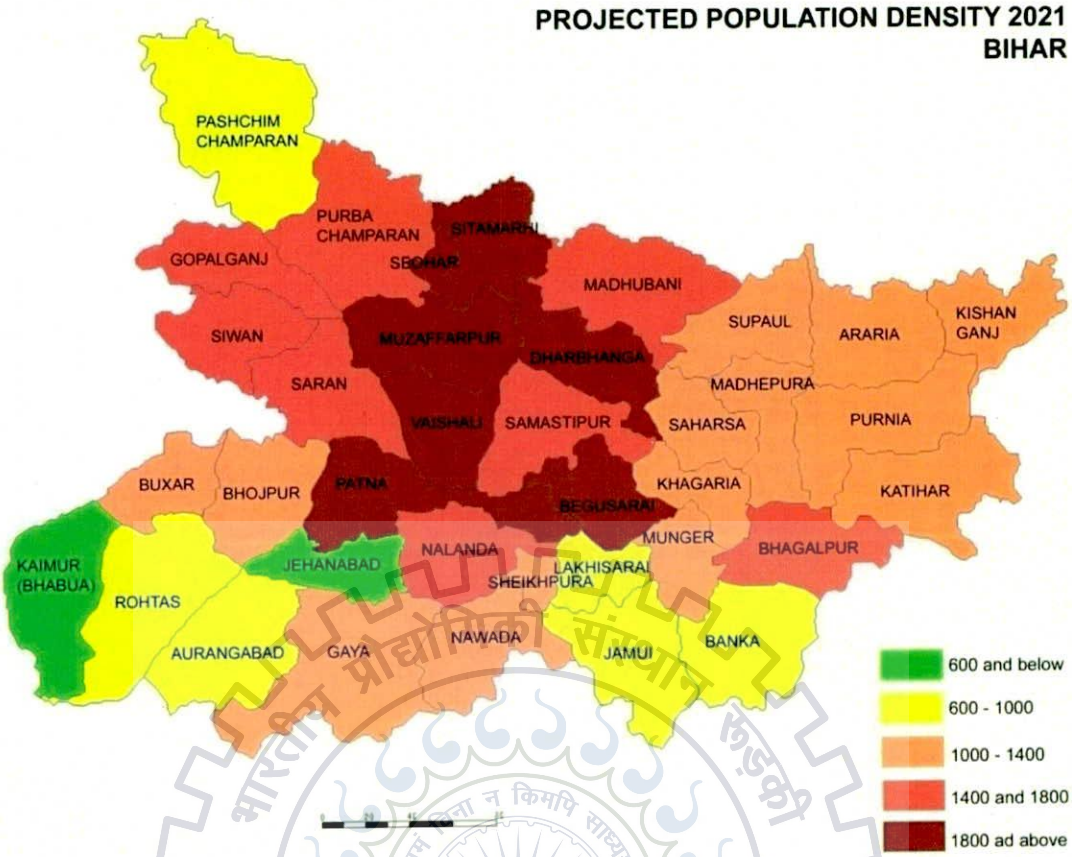


Figure 26: Projected Population Density of Bihar, 2021

In the year 2021, Projected Population density are observed in Patna, Vaishali, Muzzaffarpur, Sitamarhi, Seohar, Darbhanga and Begusarai of about more than 1800 persons per sq. km. while Kaimur and Jehanabad have the least density of population of less than 600 persons per sq. km. Among all districts Sitamarhi, Seohar, Muzzarpur, Dharbhanga and Madhubani is also coming under intensity IX and X as per 1934 Earthquake intensities. Thus there are large possibilities of heavy damage in these districts of Bihar because of Large population and large construction.

5.6 Housing Profile

The data in 2001 and 2011 Housing Census classifies the various building types based on wall material and roof material which are considered most important in the damaging impacts of earthquakes, floods and cyclonic winds. In this study the impact of earthquake intensities has only been considered. [9]

5.6.1 Wall Material Classification

- A1: Mud & Un-burnt Brick Wall
- A2: Stone Wall
- B: Burnt Brick Wall
- C1: Concrete Wall
- C2: Wood Wall
- X: Other Material

*Refer **Annexure** 7 for Distribution of Houses in Bihar by Predominant material of Wall.*

5.6.2 Roof Material Classification

- R1: Light Weight (Glass, Thatch, Bamboo, Wood, Mud, Plastic, Polythene, G1 Metal, Asbestos sheets, Other Materials)
- R2: Heavy Weight (Tiles, Slate)
- R3: Flat Roof (Brick, Stone, Concrete)

*Refer **Annexure** 8for Distribution of Houses in Bihar by Predominant material of Roof.*

The total number of different type of housing as explained above has been shown in ***Annexure 9 and 10***as per Census of Housing 2001 and 2011.

The estimation of the population living in different type of House is given in **annexure 11** and brief of the same is shown in the given figure. [9]

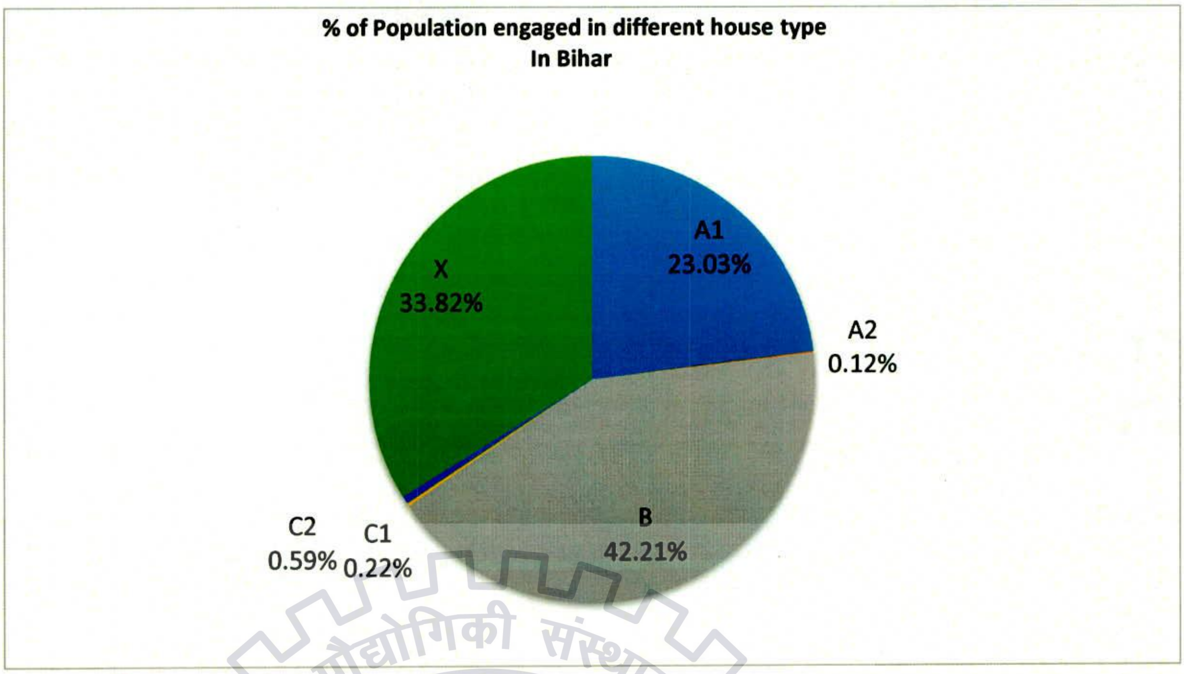


Figure 27: % Population engaged in different house type in various districts of Bihar

*Refer **Annexure 11** for Population engaged in different house type in various districts of Bihar.*

5.7 Landuse Study of Bihar

The Land use Map of Bihar for the year 2011-2012 has been shown below, that includes the following data

- Built-up or Settlement
- Road network
- Agricultural Land
- Forest,
- Water bodies etc.

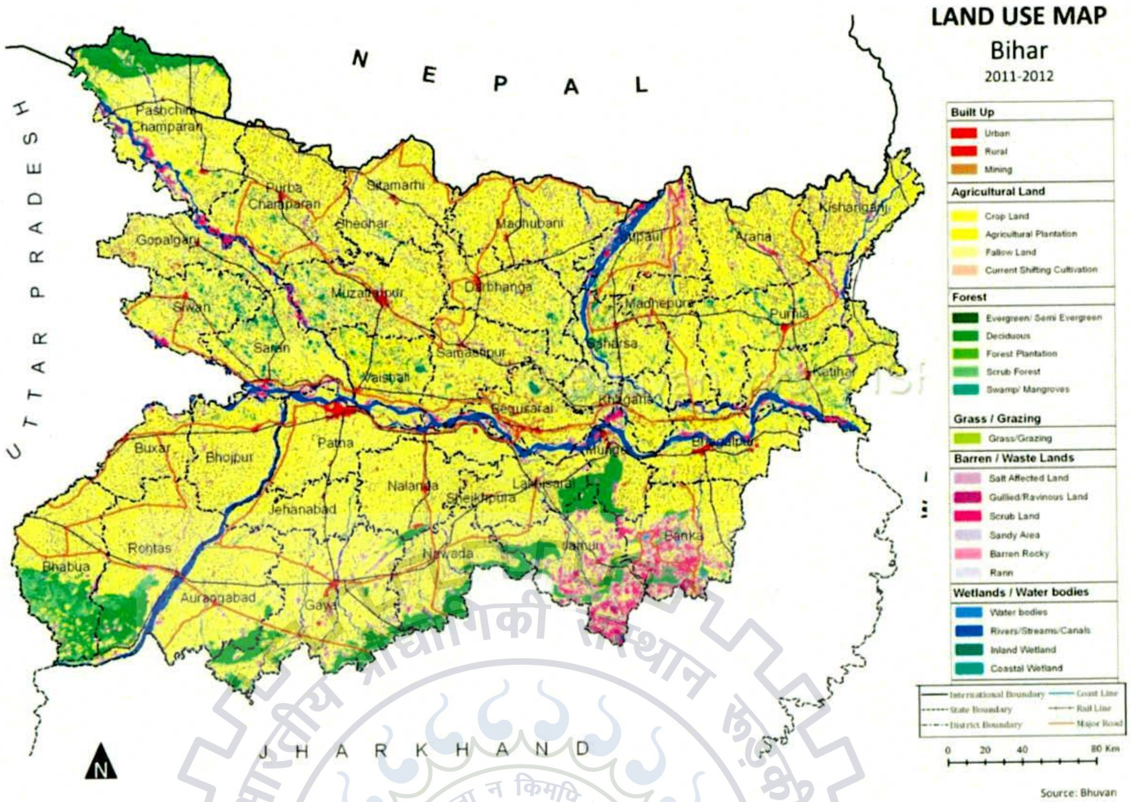


Figure 28: Landuse Map of Bihar, 2011-2012

Refer Map 3 for more details

5.8 Combining Demographic Data with Housing Data

Table 21: Distribution of different house type in various districts of Bihar

DISTRICT	A1 (%)	A2 (%)	B (%)	C (%)	C2 (%)	X (%)
PASHCHIM CHAMPARAN	5.42	0.03	30.68	0.06	1.04	62.77
PURBA CHAMPARAN	9.61	0.07	39.48	0.05	0.68	50.11
SHEOHAR	4.94	0.03	26.63	0.05	1.01	67.35
SITAMARHI	15.09	0.04	38.84	0.05	1.19	44.78
MADHUBANI	18.68	0.04	31.18	0.11	0.47	49.52
SUPAUL	2.87	0.04	12.89	0.05	0.53	83.62
ARARIA	1.51	0.05	9.05	0.03	0.46	88.91
KISHANGANJ	2.58	0.03	11.24	0.08	0.29	85.78
PURNIA	2.92	0.04	12.24	0.05	0.35	84.39
KATIHAR	12.92	0.03	16.26	0.04	0.45	70.3
MADHEPURA	6.31	0.02	17.79	0.04	0.3	75.54

SAHARSA	11.67	0.03	30.21	0.07	0.52	57.51
DARBHANGA	17.97	0.09	49.15	0.15	0.57	32.08
MUZAFFARPUR	7.85	0.04	45.53	0.16	1.17	45.26
GOPALGANJ	5.89	0.03	57.81	0.07	1.05	35.14
SIWAN	11.6	0.06	71.47	0.15	0.61	16.11
SARAN	15.8	0.05	69.4	0.16	1.4	13.19
VAISHALI	18.74	0.1	51.27	0.32	0.82	28.75
SAMASTIPUR	11.73	0.03	54.45	0.15	1.33	32.3
BEGUSARAI	23.41	0.05	52.38	0.39	1.14	22.62
KHAGARIA	20.42	0.04	40.32	0.2	0.4	38.62
BHAGALPUR	32.22	0.13	47.08	0.51	0.37	19.69
BANKA	66.06	0.09	28.26	0.21	0.16	5.22
MUNGER	33.19	0.1	53.81	0.46	0.3	12.14
LAKHISARAI	39.81	0.14	51.07	0.37	0.39	8.22
SHEIKHPURA	47.32	0.34	49.09	0.16	0.09	3.01
NALANDA	38.89	0.08	57.59	0.32	0.09	3.03
PATNA	24.13	0.31	69.58	0.94	0.28	4.77
BHOJPUR	34.85	0.28	59	0.27	0.35	5.26
BUXAR	38.22	0.21	54.83	0.14	0.41	6.19
KAIMUR (BHABUA)	59.38	0.72	37.38	0.1	0.19	2.22
ROHTAS	45.52	0.79	51.53	0.36	0.21	1.6
JEHANABAD	46.56	0.17	50	0.33	0.08	2.86
AURANGABAD	58.79	0.09	37.78	0.25	0.19	2.9
GAYA	59.7	0.25	36.71	0.35	0.09	2.89
NAWADA	55.02	0.07	42.52	0.27	0.14	2
JAMUI	66.91	0.09	29.88	0.38	0.19	2.55
BIHAR	**23.03**	**0.12**	**42.21**	**0.22**	**0.59**	**33.82**

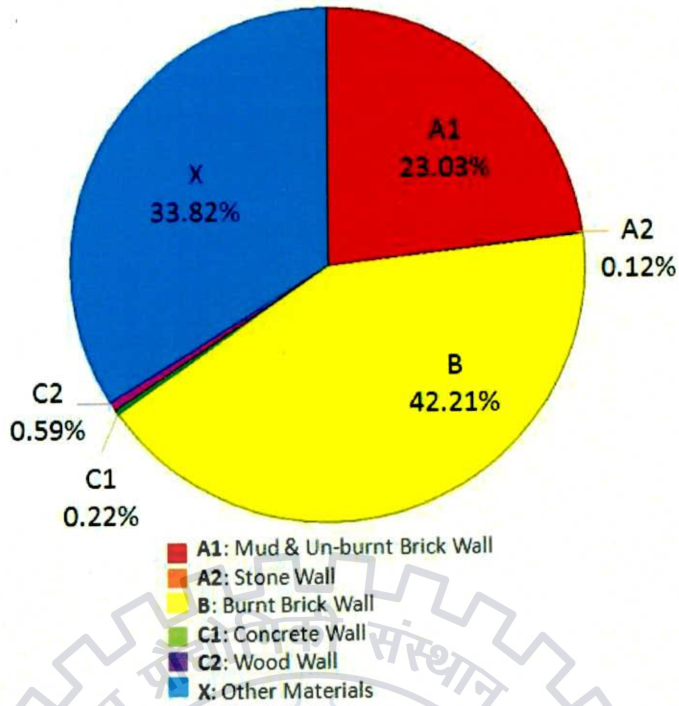


Figure 29: Distribution of Population in various house type in Bihar

5.9 Seismic Zoning Study of Bihar

The present classification of seismic zones in Bihar is in reality the outcome of the 1934 Bihar-Nepal Earthquake. Therefore, the repeat occurrence of similar intensities in a future large magnitude earthquake of the same size as in 1934 earthquake should be considered probable and the damage levels in various districts that could occur in the present building types can be worked out in a realistic manner.

Table 22: Seismic Zone Distribution

ZONE	INTENSITY	NO. OF DISTRICTS	DISTRICT'S NAME
V	MSK IX or high	8	Sitamarhi, Madhubani, Darbhanga, Saharsa,
			Supan, Madhepura, Araria and Kishanganj
IV	MSK VIII	25	E.Champaran, W.Champaran, Shivhar, Chapra, Siwan,
			Gopalganj, Muzaffarpur, Vaishali, Samastipur, Begusarai
			Khagaria, Purnia, Katihar, Bhojpur, Patna, Jahanabad
			Arwal, Nalanda, Nawada, Shekhpura, Lakhisarai,
			Jamui, Munger, Bhagalpur and Banka
III	MSK VII	5	Buxar, Khaimur, Rohtar, Aurangabad, Gaya

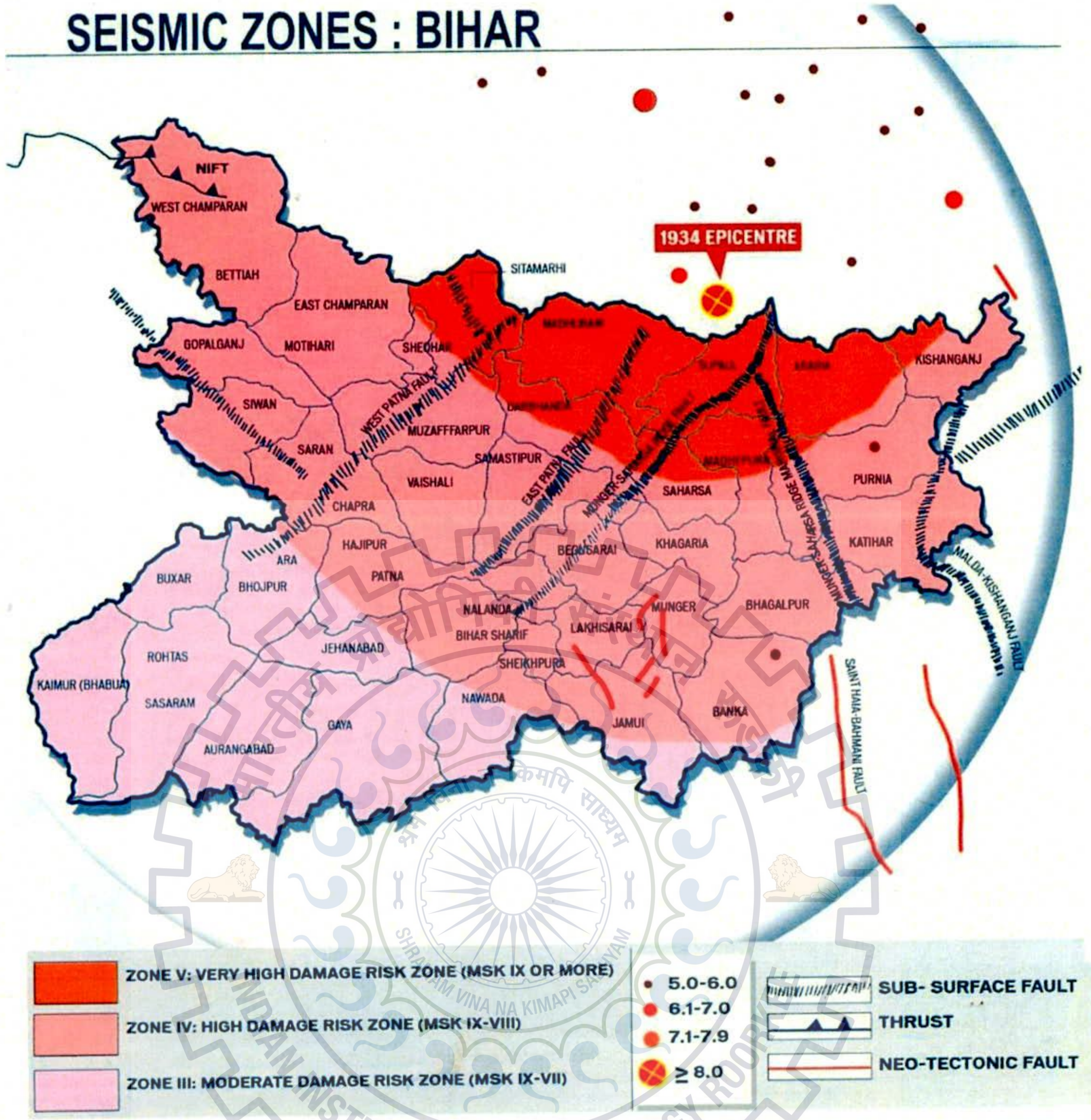


Figure 30: Seismic Zone Map of Bihar

Chapter 6

6 Damage Scenario under Great Earthquakes

6.1 Reoccurrence of 1934 Earthquake in Bihar

To find out the Population at risk, Iso-seismal Map of 1934 has been overlap on Land Use Map of Bihar, showing the following result:

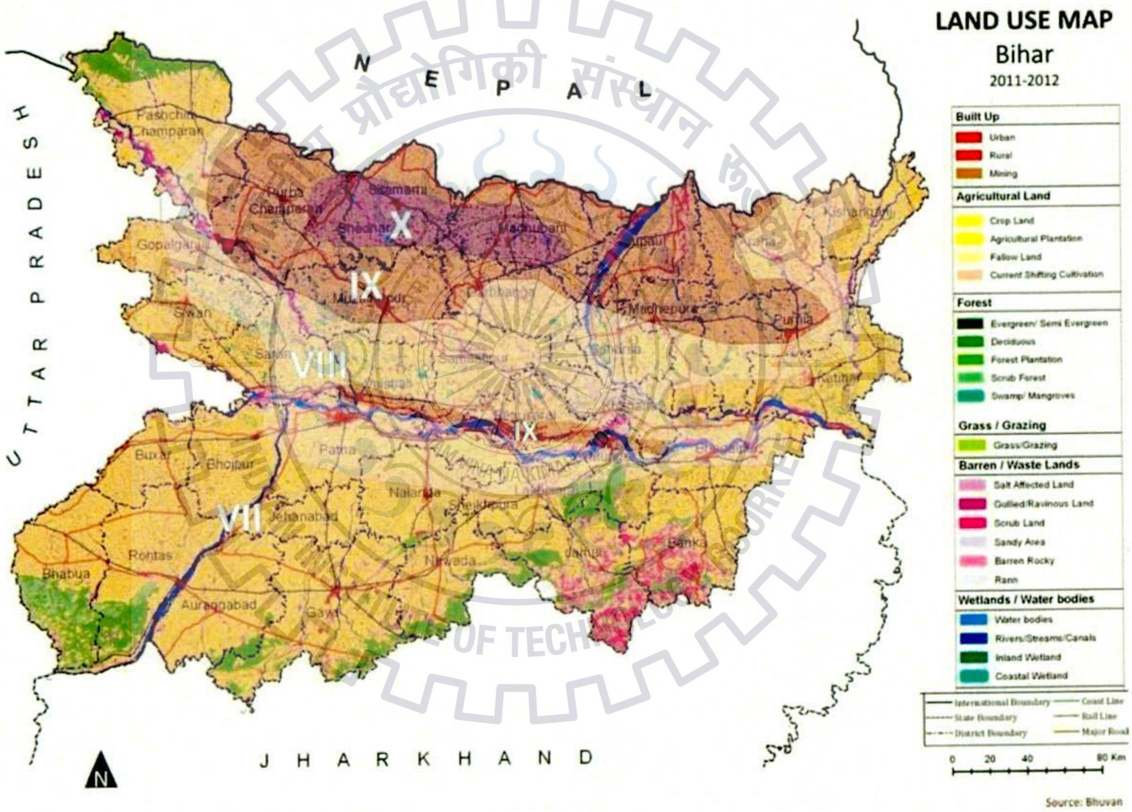


Figure 31: Iso-seimal map overlap over Landuse Map of Bihar

Refer Map 4 for more details

6.2 Expected Economic Loss as per SeisVARA

The expected Direct Economic loss for the year 2001, 2011 and 2021 (projected) had been taken out for various districts of Bihar using the SeisVARA as explained in 3.8 section of this report. The Housing data has been taken from Census of Housing, Government of India, 2001 and 2011, and for the year 2021 by projection method. There are five types of house type observed in various districts of Bihar as given in section 5.6 of this report, there are Mud Houses, Stone Houses, Burnt Brick Houses, Concrete Houses and lastly other materials that includes polythene, plastic, asbestos, grasses etc. named as X Type. X types House are least vulnerable to earthquake as they are very light weighted and cheap also. Thus X type houses are not been considered in Direct Economic loss.

The other aspects to be considered to find out direct economic loss are replacement cost and Floor area. The values for the same considered in formula are mentioned below:

Table 23: Replacement Cost and Floor Area

HOUSE TYPE	HOUSING MATERIAL	REPLACEMENT COST FOR UNIT HOUSE	FLOOR AREA FOR UNIT HOUSE
TYPE A	Mud & Stone Houses	500 Rs per sq.m	20 sq. m
TYPE B	Burnt Brick Houses	1000 Rs per sq.m	60 sq. m
TYPE C	Concrete Houses	1500 Rs per sq.m	100 sq. m

The expected economic loss for various districts of Bihar, if the 1934 earthquakes repeats in the year given are as follows:

6.2.1 Expected Economic Loss for the year 2001

Table 24: Expected Economic Loss in various districts of Bihar, 2001

BIHAR	1934 EQ.	2001	EXPECTED ECONOMIC LOSS	
DISTRICTS	INTENSITY	TOTAL HOUSES	LOWER BOUND (Cr.)	UPPER BOUND (Cr.)
PASHCHIM CHAMPARAN	VII	653725	2251	4350
PURBA CHAMPARAN	IX	795128	25188	35195
SHEOHAR	X	105889	2971	3394
SITAMARHI	X	584439	24517	27787
MADHUBANI	X	749373	25640	28775
SUPAUL	IX	387341	4089	5777
ARARIA	VIII	480586	2331	3408
KISHANGANJ	VII	315136	412	790

PURNIA	IX	555415	5527	7770
KATIHAR	VII	517149	1352	2443
MADHEPURA	IX	308108	4495	6258
SAHARSA	VIII	311547	5240	7604
DARBHANGA	IX	708041	28487	39562
MUZAFFARPUR	IX	778496	28321	39851
GOPALGANJ	VIII	389003	11558	16889
SIWAN	VII	462103	3618	7022
SARAN	VIII	558264	20686	30134
VAISHALI	VIII	471430	13409	19468
SAMASTIPUR	VIII	696581	20242	29506
BEGUSARAI	IX	487834	21521	29976
KHAGARIA	VIII	265541	6139	8881
BHAGALPUR	VIII	459390	13014	18762
BANKA	VII	309839	2469	4152
MUNGER	VIII	229496	7285	10514
LAKHISARAI	VIII	158749	4984	7170
SHEIKHPURA	VII	105156	893	1595
NALANDA	VIII	463005	15899	22909
PATNA	VIII	876201	33576	48750
BHOJPUR	VII	380182	3224	5932
BUXAR	VII	239339	1995	3636
KAIMUR (BHABUA)	VII	242317	2026	3494
ROHTAS	VII	458736	3965	7113
JEHANABAD	VII	279050	2378	4255
AURANGABAD	VII	350284	2911	5031
GAYA	VII	601129	4986	8588
NAWADA	VII	322513	2729	4777
JAMUI	VIII	260021	6496	9158

The detailed expected economic loss in various house type in various districts of Bihar for the year 2001 are briefly described in the ***annexure 12.***

6.2.2 Expected Economic Loss for the year 2011

Table 25: Expected Economic Loss in various districts of Bihar, 2011

BIHAR	1934 EQ.	2011	EXPECTED ECONOMIC LOSS	
DISTRICTS	INTENSITY	TOTAL HOUSES	LOWER BOUND	UPPER BOUND
PASHCHIM CHAMPARAN	VII	846246	2914	5631
PURBA CHAMPARAN	IX	1030175	32633	45597

SHEOHAR	X	135044	3789	4328
SITAMARHI	X	749066	31417	199849
MADHUBANI	X	942726	32244	202215
SUPAUL	IX	494252	5219	7374
ARARIA	VIII	636165	3086	4511
KISHANGANJ	VII	411289	538	1031
PURNIA	IX	714286	7104	9983
KATIHAR	VII	664724	1738	3140
MADHEPURA	IX	404396	5900	8213
SAHARSA	VIII	392738	6606	9585
DARBHANGA	IX	848660	34144	47421
MUZAFFARPUR	IX	998241	36316	51102
GOPALGANJ	VIII	463247	13764	20112
SIWAN	VII	568339	4450	8637
SARAN	VIII	679014	25161	36653
VAISHALI	VIII	607829	17289	25102
SAMASTIPUR	VIII	869621	25271	36836
BEGUSARAI	IX	618801	27301	38026
KHAGARIA	VIII	346546	8012	11590
BHAGALPUR	VIII	574247	16268	23453
BANKA	VII	392054	3124	5253
MUNGER	VIII	276316	8771	12658
LAKHISARAI	VIII	198200	6223	8952
SHEIKHPURA	VII	127536	1083	1934
NALANDA	VIII	562043	19301	27809
PATNA	VIII	1085326	41589	60386
BHOJPUR	VII	464852	3942	7253
BUXAR	VII	291185	2427	4424
KAIMUR (BHABUA)	VII	306833	2565	4424
ROHTAS	VII	554348	4792	8596
JEHANABAD	VII	339974	2897	5184
AURANGABAD	VII	444069	3691	6378
GAYA	VII	762322	6323	10891
NAWADA	VII	395648	3348	5860
JAMUI	VIII	327822	8189	11546

The detailed expected economic loss in various house type in various districts of Bihar for the year 2011 are briefly described in the ***annexure 13.***

6.2.3 Expected Economic Loss for the year 2021

Table 26: Expected Economic Loss in various districts of Bihar, 2021

BIHAR	1934 EQ.	2021	EXPECTED ECONOMIC LOSS	
DISTRICTS	INTENSITY	TOTAL HOUSES	LOWER BOUND (Cr.)	UPPER BOUND (Cr.)
PASHCHIM CHAMPARAN	VII	1038073	3574	6908
PURBA CHAMPARAN	IX	1265679	40093	56022
SHEOHAR	X	164255	4609	5265
SITAMARHI	X	913970	38334	43444
MADHUBANI	X	1135317	38831	43573
SUPAUL	IX	601570	6352	8975
ARARIA	VIII	791551	3840	5613
KISHANGANJ	VII	507721	664	1273
PURNIA	IX	872658	8679	12197
KATIHAR	VII	812235	2124	3837
MADHEPURA	IX	500792	7307	10170
SAHARSA	VIII	474202	7976	11574
DARBHANGA	IX	989171	39798	55273
MUZAFFARPUR	IX	1218061	44313	62356
GOPALGANJ	VIII	537863	15981	23352
SIWAN	VII	674418	5280	10249
SARAN	VIII	799356	29620	43149
VAISHALI	VIII	743940	21161	30723
SAMASTIPUR	VIII	1042694	30301	44167
BEGUSARAI	IX	749527	33069	46060
KHAGARIA	VIII	427670	9887	14304
BHAGALPUR	VIII	689075	19522	28143
BANKA	VII	474134	3778	6353
MUNGER	VIII	323239	10260	14808
LAKHISARAI	VIII	237752	7465	10739
SHEIKHPURA	VII	149824	1273	2272
NALANDA	VIII	661519	22717	32732
PATNA	VIII	1295125	49629	72059
BHOJPUR	VII	549186	4657	8569
BUXAR	VII	342874	2858	5209
KAIMUR (BHABUA)	VII	371320	3105	5354
ROHTAS	VII	650078	5619	10080
JEHANABAD	VII	400539	3413	6107
AURANGABAD	VII	537620	4468	7722
GAYA	VII	923146	7657	13189
NAWADA	VII	468697	3967	6942

JAMUI	VIII	395408	9878	13926

The detailed expected economic loss in various house types in various districts of Bihar for the projected year 2021 are briefly described in the ***annexure 14.***

6.3 Expected Life Loss as per SeisVARA

By studying the Demographic Profile, Housing Profile and seismic profile of various districts of Bihar for the year 2001, 2011 & 2021 and putting it into the SeisVARA, if same intensity earthquake had been repeated in the year given, as it was in 1934. The expected injuries and expected casualties as per SeisVARA are given below.

6.3.1 Expected Social Loss for the year 2001

The detailed expected social loss in various house types in various districts of Bihar are briefly described in the ***annexure 15.***

Table 27: Expected Social Loss in various districts of Bihar, 2001

BIHAR	POPULATION	1934 EQ.	EXPECTED INJURIES		EXPECTED CASUALTIES	
DISTRICTS	2001	INTENSITY	Lower Bound	Upper Bound	Lower Bound	Upper Bound
PASHCHIM CHAMPARAN	3043044	VII	29948	99020	141	275
PURBA CHAMPARAN	3933636	IX	502981	361510	81339	219647
SHEOHAR	514288	X	78289	86279	14784	38229
SITAMARHI	2669887	X	844911	987886	181363	416101
MADHUBANI	3570651	X	1185914	1431195	271535	585678
SUPAUL	1745069	IX	69926	81269	11392	30386
ARARIA	2124831	VIII	47884	108253	6737	13403
KISHANGANJ	1294063	VII	7596	18924	27	52
PURNIA	2540788	IX	99900	384567	10781	29054
KATIHAR	2389533	VII	44796	145473	216	384
MADHEPURA	1524596	IX	108515	121176	16921	48269
SAHARSA	1506418	VIII	223241	450811	35845	71382
DARBHANGA	3285473	IX	658558	733354	102390	293402
MUZAFFARPUR	3743836	IX	467387	555171	78128	200438
GOPALGANJ	2149343	VIII	212726	529152	26196	52050

SIWAN	2708840	VII	85742	193040	274	537
SARAN	3251474	VIII	70421	152258	10503	20903
VAISHALI	2712389	VIII	65028	132085	10379	20668
SAMASTIPUR	3413413	VIII	55476	120947	8190	16299
BEGUSARAI	2342989	IX	68476	136165	11164	22233
KHAGARIA	1276677	VIII	32169	63224	5305	10567
BHAGALPUR	2430331	VIII	94499	181184	15945	31765
BANKA	1608778	VII	121692	220792	21535	42915
MUNGER	1135499	VIII	45792	88501	7672	15282
LAKHISARAI	801173	VIII	38175	72546	6494	12937
SHEIKHPURA	525137	VII	29452	55256	5068	10097
NALANDA	2368327	VIII	111131	213333	18737	37326
PATNA	4709851	VIII	147484	301159	23419	46632
BHOJPUR	2233415	VII	95200	184560	15905	31682
BUXAR	1403462	VII	64694	123871	10932	21778
KAIMUR (BHABUA)	1284575	VII	89147	163558	15632	31149
ROHTAS	2448762	VII	134143	252756	22992	45809
JEHANABAD	924839	VII	50936	95761	8748	17430
AURANGABAD	2004960	VII	136378	250487	23891	47607
GAYA	3464983	VII	239659	439454	42043	83776
NAWADA	1809425	VII	115942	214502	20189	40227
JAMUI	1397474	VIII	107133	194585	18941	37745
BIHAR	**82292229**		**6581340**	**9944064**	**1161755**	**2644111**

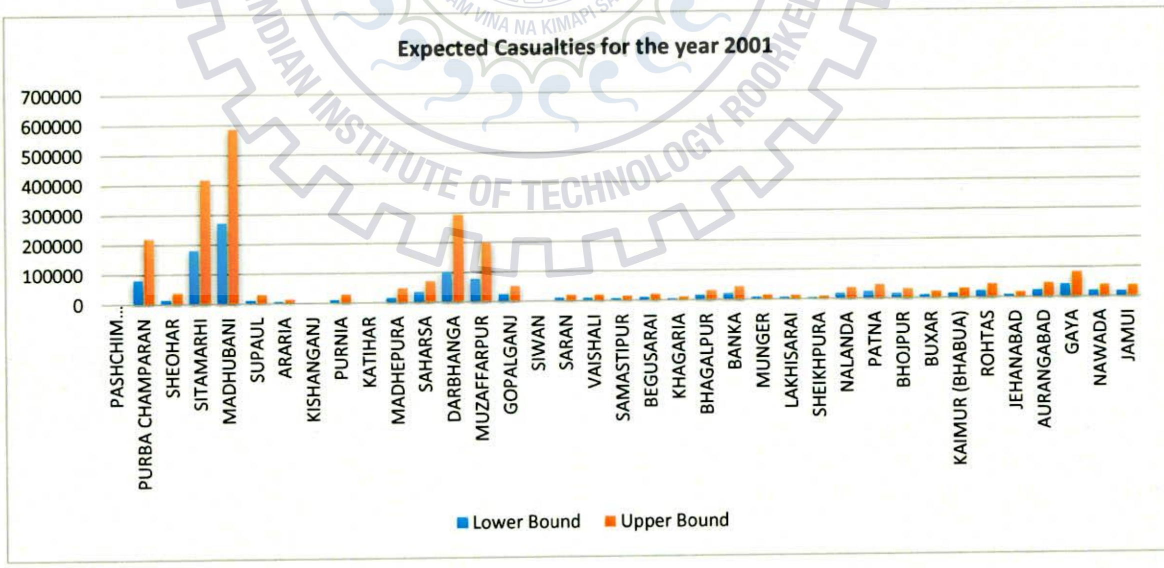


Figure 32: Expected Casualties for the year 2001, as per SeisVARA

6.3.2 Expected Social Loss for the year 2011

The detailed expected social loss in various house types in various districts of Bihar are briefly described in the ***annexure 16.***

Table 28: Expected Social Loss in various districts of Bihar, 2011

BIHAR	POPULATION	1934 EQ.	EXPECTED INJURIES		EXPECTED CASUALTIES	
DISTRICTS	2011	INTENSITY	Lower Bound	Upper Bound	Lower Bound	Upper Bound
PASHCHIM CHAMPARAN	3935042	VII	38768	128154	183	355
PURBA CHAMPARAN	5099371	IX	651567	468351	105370	284530
SHEOHAR	656246	X	99894	110099	18868	48780
SITAMARHI	3423574	X	1083057	1266359	232488	533378
MADHUBANI	4487379	X	1492180	1800859	341671	736921
SUPAUL	2229076	IX	89214	103687	14535	38767
ARARIA	2811569	VIII	63621	143703	8961	17828
KISHANGANJ	1690400	VII	9906	24664	36	68
PURNIA	3264619	IX	128451	494484	13863	37357
KATIHAR	3071029	VII	57585	187009	278	493
MADHEPURA	2001762	IX	142406	159029	22207	63343
SAHARSA	1900661	VIII	281419	568284	45186	89985
DARBHANGA	3937385	IX	789308	878942	122716	351656
MUZAFFARPUR	4801062	IX	599366	711915	100185	257042
GOPALGANJ	2562012	VIII	253330	630162	31196	61985
SIWAN	3330464	VII	105482	237525	337	661
SARAN	3951862	VIII	85623	185139	12769	25413
VAISHALI	3495021	VIII	83854	170322	13384	26652
SAMASTIPUR	4261566	VIII	69238	150960	10221	20341
BEGUSARAI	2970541	IX	86847	172700	14159	28198
KHAGARIA	1666886	VIII	41979	82505	6923	13789
BHAGALPUR	3037766	VIII	118121	226478	19931	39705
BANKA	2034763	VII	153985	279383	27250	54303
MUNGER	1367765	VIII	55137	106561	9237	18401
LAKHISARAI	1000912	VIII	47661	90573	8107	16152
SHEIKHPURA	636342	VII	35720	67014	6146	12246
NALANDA	2877653	VIII	134901	258965	22744	45309
PATNA	5838465	VIII	182693	373049	29010	57765
BHOJPUR	2728407	VII	116396	225650	19446	38737
BUXAR	1706352	VII	78700	150691	13298	26492
KAIMUR (BHABUA)	1626384	VII	112888	207116	19795	39445
ROHTAS	2959918	VII	162094	305422	27783	55354
JEHANABAD	1125313	VII	62055	116666	10658	21234

AURANGABAD	2540073	VII	172901	317568	30290	60356
GAYA	4391418	VII	303920	557292	53315	106239
NAWADA	2219146	VII	142224	263124	24765	49345
JAMUI	1760405	VIII	135065	245317	23880	47586
BIHAR	**103398609**		**8267556**	**12465722**	**1461193**	**3326210**

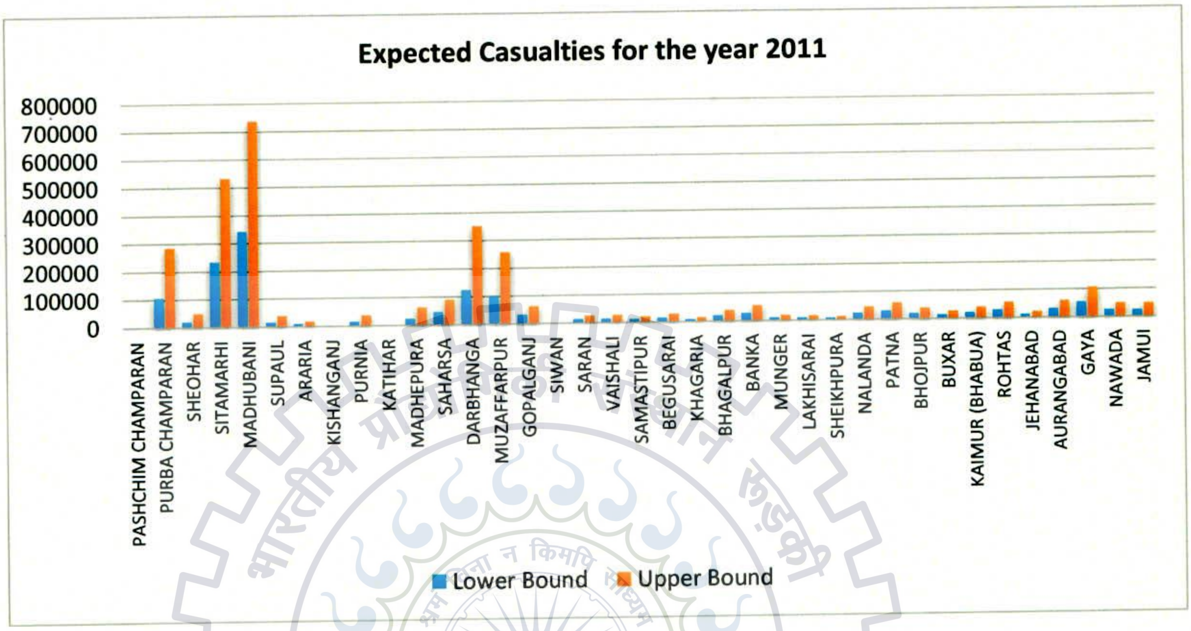


Figure 33: Expected Casualties for the year 2011, as per SeisVARA

6.3.3 Expected Social Loss for the year 2021

The detailed expected social loss in various house types in various districts of Bihar are briefly described in the ***annexure 17.***

Table 29: Expected Social Loss in various districts of Bihar, 2021

BIHAR	POPULATION	1934 EQ.	EXPECTED INJURIES		EXPECTED CASUALTIES	
DISTRICTS	2021	INTENSITY	Lower Bound	Upper Bound	Lower Bound	Upper Bound
PASHCHIM CHAMPARAN	4827040	VII	47556	157204	224	436
PURBA CHAMPARAN	6265106	IX	800518	575418	129458	349574
SHEOHAR	798204	X	121503	133915	22950	59332
SITAMARHI	4177261	X	1321488	1545143	283669	650799
MADHUBANI	5404107	X	1797017	2168757	411471	887467
SUPAUL	2713083	IX	108585	126201	17691	47185
ARARIA	3498307	VIII	79160	178803	11150	22182
KISHANGANJ	2086737	VII	12229	30446	44	83

PURNIA	3988450	IX	156932	604121	16937	45640
KATIHAR	3752525	VII	70364	228508	339	602
MADHEPURA	2478928	IX	176352	196937	27500	78443
SAHARSA	2294904	VIII	339792	686160	54559	108650
DARBHANGA	4589297	IX	919993	1024468	143034	409880
MUZAFFARPUR	5858288	IX	731350	868683	122247	313645
GOPALGANJ	2974681	VIII	294134	731664	36220	71969
SIWAN	3952088	VII	125170	281859	400	785
SARAN	4652250	VIII	100798	217952	15032	29916
VAISHALI	4277653	VIII	102631	208461	16381	32620
SAMASTIPUR	5109719	VIII	83018	181005	12255	24389
BEGUSARAI	3598093	IX	105194	209185	17150	34155
KHAGARIA	2057095	VIII	51806	101819	8544	17017
BHAGALPUR	3645201	VIII	141741	271764	23917	47644
BANKA	2460748	VII	186223	337873	32955	65671
MUNGER	1600031	VIII	64500	124657	10806	21525
LAKHISARAI	1200651	VIII	57172	108648	9725	19375
SHEIKHPURA	747547	VII	41962	78725	7220	14386
NALANDA	3386979	VIII	158778	304800	26770	53329
PATNA	6967079	VIII	436017	890323	69244	137888
BHOJPUR	3223399	VII	137513	266588	22974	45764
BUXAR	2009242	VII	92670	177440	15659	31195
KAIMUR (BHABUA)	1968193	VII	136613	250645	23956	47735
ROHTAS	3471074	VII	190087	358166	32581	64913
JEHANABAD	1325787	VII	73110	137450	12556	25017
AURANGABAD	3075186	VII	209325	384470	36671	73071
GAYA	5317853	VII	368036	674861	64563	128652
NAWADA	2628867	VII	168482	311704	29337	58456
JAMUI	2123336	VIII	162910	295893	28803	57397
BIHAR	**124504989**		**10170731**	**15430717**	**1794994**	**4076786**

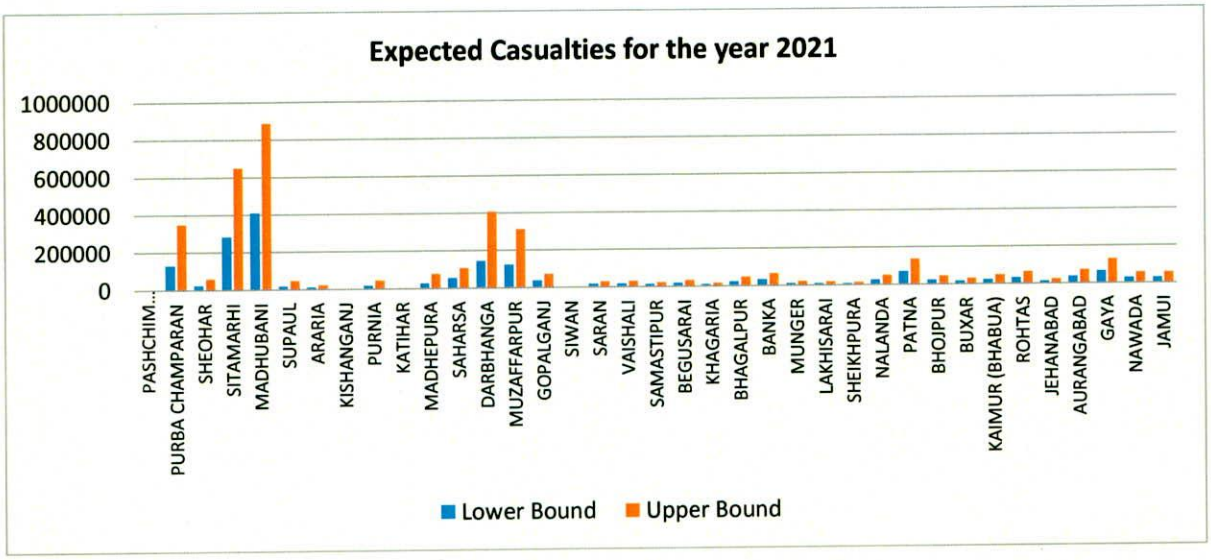


Figure 34: Expected Casualties for the year 2021, as per SeisVARA

6.4 Remarks

- Madhubani, Sitamarhi and Sheohar are coming under Intensity X as per 1934 earthquake, thus have the possibilities of very high losses and damage.
- Madhubani can have the highest loss among all the districts of Bihar as its coming in zone V, High population density and most important East Patna Fault is passing through it. Earthquake Resilient Buildings should be made compulsory over here. Old structures should be retrofit and new construction should be under expert's supervision.
- Sitamarhi and Sheohar are also coming under intensity X as per 1934 earthquake which is highly risk zone as per earthquake is consider and also have high population density.
- Reason observed for high damage in Darbhanga district of Bihar are East Patna fault is passing through it, it's also coming under the slump belt area as per 1934, Its also have high population density and also as per 2021 population projection, it will come under one of the high population density district of Bihar.
- Very high damages were also observed in Muzzaffarpur district of Bihar; due to Sub-surface fault namely West Patna Fault passing through it, it's coming under the slump

belt area as per 1934, one of the highly populated areas. Thus earthquake resilient buildings should also be made compulsory by the government strictly.

- Patna the capital of Bihar, Highly populated district of Bihar and due to high population density there is no open gathering spaces, where people can get rescue. The government should limit the construction at Patna as it is already overpopulated. Proper Master Planning and Disaster Mitigation & Management Plan should be followed.
- 'Gaya' is the district of Bihar where 60% of their total houses were coming under House Type i.e. Mud houses. Thus Mud Houses were very vulnerable to high intensity earthquake.
- Damages were also observed at Supaul, Araria and Madhubani as these districts of Bihar were very close to the epicentre of 1934 Earthquake. But due to less population density, damage was much lesser compare to Darbhanga and Muzzaffarpur etc.
- Infact as per housing data 2001, 33.54% of the total houses were coming under House Type X i.e. Plastic/Polythene, Asbestos, Metal sheets etc. Government should take proper steps for these people also and provide them proper EWS.

Chapter 7

7 Proposals & Recommendations

The damage scenario under great earthquakes based on expected economic loss and social loss observed in Bihar shows that if the earthquake of 1934 repeats in future years, it can cause great damage. As earthquake cannot be predicted and its frequency is also increasing, Preparedness is the only way to minimize the loss. There is the need to take action against prevention and mitigation of disaster, by the departments of the government at the state level, district level and local level. Some of the proposals & recommendations at different level are given below:

Government's Role:

Government plays a major role in the mitigation as well as management part for the state to respond to any threatening disaster situation or disaster.

- Government should encourage the custom of Disaster Management Plan for every district, describing the identified vulnerable area, mitigation measure, management strategies, awareness programs, role of various department and at local level.
- Disaster Awareness should be made compulsory at school, college, offices as well as for local people with mock drills and training programs
- The capacity-building and preparedness measures
- Response Plans and procedures for:
    - District-wise allotment of responsibilities to the departments
    - Prompt response to disaster and relief thereof;
    - Procurement of essential resources;
    - Establishment of communication links
    - The distribution of information to the public
- Strengthening early warning system for different disasters at the district level.
- The roles and responsibilities for the different stakeholders during different disasters
- The roles and responsibilities for different government department at the time of disasters

Disaster Management Plan Guidelines to be followed

- Study of the area before preparing the DM Plan:
  - Study of Demographic Profile that includes Growth Rate, population density etc.
  - Study of Past Disasters in that area.
  - Identification of Natural Resources available
  - Study of Housing Data that includes house type, material used etc.
  - Land-use study to measure built up area
  - Seismic study of the area
  - Geological study
  - Identification of Vulnerable area, population and housing
- Re-strengthening of existing structure
- Construction of new structure with earthquake resistant
- Re-strengthening of life-line building such as hospitals, schools and lifeline structure such as bridges etc.
- Generation of Resource Maps
  - All lifeline building location that includes Govt. Hospitals & Schools, Semi-Govt. Hospitals & Schools, Private Hospitals & Schools.
  - Road map with shortest route optimization techniques.
  - Location of most Vulnerable area for disasters
  - Location of first reaction forces (FRF) like police station, fire station etc.
  - Most vulnerable populated area.
  - All alternative routes information which contains optimal distance parameter and creating efficient networking between all lifeline buildings
- Plant more and more trees

Advance District Disaster Management Plan

DDMP is the need for every district now. As there are interventions of technologies in every sector, thus there should be Advance DDMP for every district. Advance DDMP may include following feature:

- Make DDMP self-equipped to maintain and upgrade DDMP.

- There should be plan for establishment of incidence command system with unified manner.
- Working of DDMP and SDMP should be upgraded by development of interactive system which will be useful to reinforce the working capacity as well as response mechanism.
- DDMP should be properly framed showing working of action plan for implementation.
- Preparation of Web base software to maintain and upgrade plan time to time.
- DDMP with data base updating facilities at specified Interval.
- DDMA can produce upgraded plan by inputting various parameters in it like change in demographic data, land-use etc.
- Separate login facility for back-end so that only authorized person only can update information.
- Proposal and time frame for different online/network based on system which is based on GIS, helping in quick decision making by concern authorities.
- Frame work of action plan for different maps creation like
    - Generation of Disaster Management Resources District Maps
    - Generation of Hazard and Vulnerability District Maps
    - Generation of Supply Chain Management and Resource Mobilization maps
    - Location of Hospitals, Schools on map and nearest escape route
- Frame work of capacity building online based system with self learning process.

UDPFI Guidelines to be followed

- Flood plain: No settlement near water bodies up to ½ km from flood-plain or modified flood-plain affected by dam in the upstream or by flood control systems.
- Industry: No settlement around the industries
- The green buffer shall be ½ km wide around the battery limit of the industry. For industry having odor problem it shall be a kilometer wide.
- The following tables describe the No. of life line buildings to be there for the given population.

Table 30: UDPFI Guidelines for Health care facilities

HEALTH CARE FACILITIES	FOR EVERY POPULATION OF	NO. OF CENTERS	AREA (ha)	NO. OF BEDS
General Hospitals	2,50,000	1	6.0 ha	500
Intermediate Hospitals (Categogy A)	1,00,000	1	3.7 ha	200
Intermediate Hospitals (Categogy B)	1,00,000	1	1.0 HA	80
Poly Clinic	1,00,000	1	0.2 - 0.3 ha	
Nursing Home, Child welfare and Maternity Centre	45,000 - 1,00,000	1	0.2 - 0.3 ha	25 - 30
Dispensary	15,000	1	0.08 - 0.12 ha	

Table 31: UDPFI Guidelines for Educational Centers

EDUCATIONAL CENTERS	FOR EVERY POPULATION OF	NO. OF CENTERS	AREA (ha)	NO. OF STUDENTS
Pre-Primary School (nursery)	2500	1	0.08 ha	
Primary School (Class I to V)	5000	1	0.4 ha	500
Senior Secondary School (Class VI to XII)	7500	1	1.6 ha	1000
Integrated School (Class I to XII)	90,000 - 1,00,000	1	3.5 ha	1500
College	1,00,000 - 1,25,000	1	4.0 ha	1000 - 1500
Technical Education Centre	10,00,000	1	4.0 ha	500

Codes Implementations

- Building Codes developed by Bureau of Indian Standards(BIS) should be get updated.
- It is reported that as per BIS Code Building is designed for earthquake load of around 10% of vertical load. While as per available information, U.S. and Chilean Seismic Design Codes provide for 21% and 24% of vertical load as earthquake forces.
- BIS Codes for Earthquake should be revised based on the performance, existing conditions etc.

- Updated Seismic Safety Codes and standards should be place in the public domain for easy availability including the Internet for free downloads. It has been observed that lack of knowledge about the building codes and also the lack of availability are responsible for poor implementation of earthquake resistant construction practices.
- It shall be useful if BIS prepare commentaries and explanatory handbooks for all the codes already published, in particular, the recently published codes to facilitate easy understanding of the provisions by practitioners, teachers, students and public at large.

Structural Safety of Buildings

One of the major reasons for extreme damage during 1934 earthquake was liquefaction. Many of the buildings were constructed on the slump belt in Bihar. Structure where we are should be that strong that it resists the earthquake force and people living should feel safe while they are inside any building.

Earthquake never kills, but building does!

- It is of paramount and urgent importance to examine the structural safety of buildings built on stilts in view of the fact that a large number of existing buildings in major cities and urban agglomeration are constructed on stilts providing houses for huge population belonging to various income groups.
- Use of existing buildings should guaranty their structural safety, if not then there should be remedial alternatives for strengthening of existing buildings and it should be practicable.
- There should be provision in code not to construct unsafe buildings.

Retrofitting of Buildings

The most of the building in Bihar is vulnerable to collapse in the event of high intensity earthquakes. Re-strengthening of existing building i.e. by retrofitting we can strengthen the building.

- Retrofitting of the Life-line building including hospitals, schools etc. of the districts should be the concern. As they places an important role during a disaster.

- Seismic Vulnerable Assessment, namely Rapid Visual Screening (RVS) and Detailed Vulnerable Assessment (DVA) should be promoted specially in old buildings.
- In view of above, there is a requirement to make strategy to deal with this gap so that vulnerability of majority of buildings can be assessed and retrofitting design is available with ease and economy so that retrofitting of at least critical lifeline structures are taken up by Central/State Government and public at large are also encourage to undertake retrofitting of their property to make them seismically resilient.
- Experts may also examine the Retrofitting Guideline prepared by NDMA constituted Core Group and recommended requirement of any change thereof

Rural Development

Most of the population in Bihar is residing in Rural Areas. Thus enforcement of earthquake/ disaster resilient construction in Rural Areas is must under control of Punchayati Raj System.

- Due to impact of industrialization and urbanization more and more villages are emitting urban ways of construction but creating non engineered assets and liable to undergo large scale damages during earthquake of moderate to large intensities.
- In this regards the Gram-Punchayats may play a role of advisor or controller to propagate and ensure earthquake/disaster resilient construction.
- Experts may examine this aspect and come out with their recommendation.

PREPAREDNESS

- Early Warning System
- Retrofitting of Lifeline Buildings
- Codes Implementation
- Planning Byelaws Implementation
- Change in Byelaws
- Micro zonation of Study Area
- DM Plan preparation of Risk Zones
- Real Time Data Generation

AWARENESS

- Mock Drill
- IEC (Information, Education & Communication)
- Awareness Programs

RESPONSE

- Zone wise DM Plan response Guidelines
- Management System
- Rescue Operation
- Transportation System
- Medical Facilities
- Evacuation Plan
- Lifeline Building

Public Awareness

The promoting concept of conducting awareness programs for the general public about Earthquake safety and precautions at different levels such as Schools, Colleges, community etc. by the following way,

- Mock drills
- Training Programs
- Street Plays
- Awareness programs
- Workshops

Chapter 8

8 Conclusion

This study estimate the probable damages, Economic lost, loss of lives, expected injuries that may occur in various districts of Bihar, if 1934 earthquake intensity repeats in the recent years. Damage scenario under hypothetical recurrence of 1934 earthquake intensities has been estimated in the form of expected economic loss and social loss for various districts of Bihar using an open source software tool named SeisVARA (Seismic Vulnerability and Risk Assessment of Housing) in order to assess the seismic risk of housing stock.

The projected damage scenario highlights the absolute seriousness of the situation given the present building stock and demands that all new construction in Bihar, without any exception, must be earthquake resistant and the existing critical and large occupancy buildings need to be surveyed and retrofitted, if required.

The main reason observed for deep loss and damages in some of the districts of Bihar such as Sitamarhi, Madhubani, Darbhanga, Muzzaffarpur, Patna are high Population Density, Zone V, close to epicentre, construction on the slump belt, Weak Houses to face the higher intensities, no planning, no guidelines and building codes followed etc.

In view of the huge number of probable loss of human lives during postulated earthquake and heavy economic loss as well in the projected year 2021, the following measures are suggested to be taken urgently:

- All new construction of housing should be earthquake resilient as per BIS codes in India.
- The housing constructed without sufficient earthquake resisting elements, should be surveyed and retrofitted if required.
- A special legislation along with special team of private-public organization may be entrusted to accomplish the above task.
- Preparation of District Disaster Management Plan.
- Disaster Awareness at all level for the public.

The main endeavour of this study is to estimate the Damage Scenario under hypothetical recurrence of 1934 Earthquake intensities in various districts of Bihar and prepare Bihar to face upcoming earthquakes with minimum loss.

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Annexure 1: Classification of Module Building Type as per SeisVARA

SeisVARA-Intensity (V.1.0)

CLASSIFICATION OF MBTs

S. No.	Model Building Type (MBT)	Description of Model Building Type (MBT): Wall/Framing Type	Roof/ Floor Type	No. of Stories	Most likely Vulnerability Class as per existing classifications as per EMS
Adobe and Random Rubble Stone Masonry					
1	AM1	Rammed mud / sun-dried bricks/ rubble stones in mud mortar	R2	1-2	A
2	AM2		R1	1-2	
3	AL1	Rubble stones in lime-surkhi mortar	R2	1-2	
4	AL2		R1	1-2	
5	AL3		R1	1-2	
6	AC1	Rubble stones in cement mortar	R2	1-2	
7	AC2		R1	1-2	
8	AC3		R3	1-2	
Masonry consisting of Rectangular Units					
9	MM1	Burnt clay bricks / rectangular stones in mud mortar	R2	1-2	
10	MM2		R1	1-2	
11	MM3		R1	1-2	
12	ML1	Burnt clay bricks / rectangular stones in lime-surkhi mortar	R2	1-2	B
13	ML2		R1	1-2	
14	ML3		R3	1-2	
15	MC1	Burnt clay bricks / rectangular stones / concrete blocks in cement	R2	1-2	
16	MC2		R1	1-2	

17	MC3L	mortar	R3	1-2	C
18	MC3M			3+	
19	ME1L	Burnt clay bricks / rectangular stones / concrete blocks in cement mortar and provided with seismic bands and vertical reinforcement at corners and jambs	R1	1-2	
20	ME1M			3+	
Framed Structures					
21	RC1L	RC frames/shear walls with URM infills – constructed without any consideration for earthquake forces	R3	1-3	
22	RC1M			4-7	
23	RC2L	RC frames/shear walls with URM infills - earthquake forces considered in design but detailing of reinforcement and execution not as per earthquake-resistant guidelines (low-code / moderate-code)		1-3	D
24	RC2M			4-7	
25	RC2H			8+	
26	RC3L	RC frames/shear walls with URM infills - designed, detailed and executed as per earthquake-resistant guidelines (low-code / moderate-code / high-code)		1-3	E
27	RC3M			4-7	
28	RC3H			8+	
29	ST1L	Steel moment frames with URM infills (low-code / moderate-code / high-code)		1-3	
30	ST1M			4-7	
31	ST1H			8+	
32	ST2L	Steel braced frames (low-code / moderate-code / high-code)		1-3	
33	ST2M			4-7	
34	ST3H			8+	

Annexure 2: Damage Probability Matrix

LOWER-BOUND AND UPPER-BOUND DAMAGE PROBABILITY MATRICES (DPM) *(acc. to Prasad et al., 2009 based on MSK-EMS and Arya, 2006)*											
		Damage Probability (%)									
		Lower-Bound Damage Scenario					Upper-Bound Damage Scenario				
Proposed MBT	MSK/ EMS Intensity	D1	D2	D3	D4	D5	D1	D2	D3	D4	D5
A	VI	15	10	0	0	0	55	20	0	0	0
	VII	18	17	55	10	0	0	0	80	20	0
	VIII	0	18	17	55	10	0	0	0	80	20
	IX	0	0	43	42	15	0	0	23	22	55
	X	0	0	0	45	55	0	0	0	0	100
	XI	0	0	0	0	100	0	0	0	0	100
	XII	0	0	0	0	100	0	0	0	0	100
B	VI	15	10	0	0	0	55	20	0	0	0
	VII	75	15	10	0	0	25	55	20	0	0
	VIII	0	35	55	10	0	0	0	80	20	0
	IX	0	0	75	15	10	0	0	25	55	20
	X	0	0	43	42	15	0	0	23	22	55
	XI	0	0	23	22	55	0	0	0	0	100
	XII	0	0	0	0	100	0	0	0	0	100
C	VI	10	0	0	0	0	20	0	0	0	0
	VII	52	10	0	0	0	67	20	0	0	0
	VIII	35	55	10	0	0	0	80	20	0	0
	IX	0	75	15	10	0	0	25	55	20	0
	X	0	0	75	15	10	0	0	25	55	20

	XI	0	0	30	55	15	0	0	0	45	55
	XII	0	0	0	0	100	0	0	0	0	100
D	VII	0	0	0	0	0	15	0	0	0	0
	VIII	0	0	0	0	0	0	15	0	0	0
	IX	85	15	0	0	0	30	55	15	0	0
	X	0	75	15	10	0	0	25	55	20	0
	XI	0	0	75	15	10	0	0	25	55	20
	XII	0	0	0	45	55	0	0	0	0	100
E	IX	100	0	0	0	0	85	15	0	0	0
	X	75	15	10	0	0	25	55	20	0	0
	XI	0	75	15	10	0	0	25	55	20	0
	XII	0	0	35	10	55	0	0	0	20	80

Annexure 3: Type of Census Housing

1. **Rural-Urban Areas**

The unit of classification for urban areas is 'town' and for rural areas is 'villages'. The definition of urban area includes the following:

- All places with a municipality, corporation, cantonment board or notified town area etc.
- A place satisfying the following three criteria simultaneously:
  - A minimum population of five thousand people;
  - At least 75% of male working population engaged in non-agricultural pursuits;
  - Population Density of at least 400 per sq.km

Apart from these, the outgrowths (OGs) of cities and towns have also been treated as urban under 'Urban Agglomerations'

Examples of out-growths are

- railway colonies,
- university campuses,
- port areas,
- Military camps, etc.

That may have come up near a statutory town or city but within the revenue limits of a villages or villages contiguous to the town or city. Thus, the town level data, wherever presented, also included the data for outgrowths of such towns.

2. Uses of Census Houses

The different uses of census houses has been standardized and grouped into ten categories, as given below

- **Residence:** Houses entirely used for residential purpose.
- **Residential-cum-other use:** Commercial space in some part of residential area, example: residence-cum-grocery shop or workshop (book binding) or boarding house, etc.,
- **Shop/Office:** exclusively used as shops and offices
- **School/College, etc:** All types of educational institutional and training centers without lodging facilities or any residential use.
- **Hotel/lodge/guest house, etc.:** Used completely for temporary stay and Stay for a period not more than three months.
- **Hospital/Dispensary, etc.**: Used as hospitals, dispensaries, nursing homes and such other health or medical institutes.

- **Factory/workshop/work shed, etc.:** Exclusively used for running a factory or a workshop of manufacturing, production, processing, repairing or services, etc.
- **Place of worship:** temples, gurudwaras, mosques, churches, prayer halls, etc.
- **Other non-residential use:** Used as places of entertainment and community gathering and all other non-residential miscellaneous uses not covered under any of the above categories; used as cattle-shed, godown, garage, petrol pump, power station, pump house, tube well room, cinema house, museum, stadium, etc.
- **Vacant:** Found vacant, under construction or not being used for any other non-residential purpose.

3. Type of Census Houses

These have been classified according to the types of material used in the construction of wall and roof of the house. The basis of their classification is described hereunder:

- **Permanent Houses:** Houses, the walls and roof of which are made of permanent materials. The material of walls can be any one from the following, namely, galvanized iron sheets or other metal sheets, asbestos sheets, burnt bricks, stones or concrete. Roof may be made of from any one of the following materials, namely, tiles, slate, galvanized iron sheets, metal sheets, asbestos sheet, bricks, stones or concrete.
- **Temporary Houses:** Houses in which both walls and roof are made of materials, which have to be replaced frequently. Walls may be made from any one of the following temporary materials, namely, grass, thatch, bamboo, plastic, polythene, mud, un-burnt bricks or wood. Roof may be made from any one of the following temporary materials, namely, grass, thatch, bamboo, wood, mud, plastic or polythene.
- **Semi-permanent houses:** Houses in which either the wall or the roof is made of permanent material.
- **Serviceable temporary houses:** Temporary houses in which wall is made of mud, un-burnt bricks or wood.
- **Non-serviceable temporary houses**: Temporary houses in which wall is made of grass, thatch, bamboo, plastic or polythene, etc.,

Annexure 4: Explaining Intensities of Earthquake

I. Not felt	Not felt except by a very few under especially favourable conditions.
II. Weak	Felt only by a few persons at rest, especially on upper floors of buildings.
III. Weak	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
IV. Light	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V. Moderate	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI. Strong	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII. Very Strong	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
VIII. Severe	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
IX. Violent	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X. Extreme	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.
XI. Extreme	Few, if any (masonry), structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
XII. Extreme	Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air

Annexure 5: Probable Damage stated in MSK intensities VI TO IX

(Refer IS 1893 (Part 2): 2002, Annex D) – Intensity Scales

Intensity Scale VI: Frightening

- Damage of **Grade 1** is sustained in single buildings of Type **B;**
- Damage of **Grade 1** in **many** of Type **A**;
- Damage of **Grade 2** in **few** buildings of Type **A**.

Intensity Scale VII: Damage of buildings

- In **many** buildings of Type **C** damage of **Grade 1** is caused:
- **Many** buildings of type **B** damage of **Grade 2**.
- **Most** buildings of Type **A** suffer damage of **Grade 3**,
- **Few** buildings of Type **A** suffer damage of **Grade 4**.
- Landslides of roadways on steep slopes:
- Crack in roads;
- Seams of pipelines damaged;
- Cracks in stone walls.

Intensity Scale VIII: Destruction of Buildings

- **Most** buildings of Type **C** suffer damage of **Grade 2**,
- **Few** buildings of Type **C** suffer damage of **Grade 3**,
- **Most** buildings of Type **B** suffer damage of **Grade 3**.
- **Most** buildings of Type **A** suffer damage of **Grade 4**.
- Occasional breaking of pipe seams.
- Memorials and monuments move and twist,
- Tombstones overturn,
- Stone walls collapse.

Intensity Scale IX: Heavy Damage

- **Many** buildings of Type **C** suffer damage of **Grade 3** and a **few** of **Grade 4**.
- **Many** buildings of Type **B** show damage of **Grade 4** and **few** of **Grade 5**.
- **Many** buildings of type **A** suffer damage of **Grade 5**.
- Monuments and columns fall,
- Considerable damage to reservoirs;
- Underground pipes partly broken;
- Railway lines are bent
- Roadway damaged.

[**'Most'** can be range from 60% to 90%, **'Many'** in the range of 40% to 60% and **'Few'** in the range of 5% to 15%]