# RESILIENCE OF VERNACULAR STRUCTURES TOWARDS EARTHQUAKE

## A DISSERTATION

*Submitted in partial fulfilment of the requirements for the award of the degree*

*of*

MASTER OF TECHNOLOGY

*in*

DISASTER MITIGATION AND MANAGEMENT

*By*

**PRASHANSA DIXIT**



CENTRE OF EXCELLENCE IN DISASTER MITIGATION AND MANAGEMENT
INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
ROORKEE – 247 667 (INDIA)

MAY, 2016

## CANDIDATE'S DECLARATION

I, hereby ,declare that the work which is being presented in the dissertation entitled "**Resilience of Vernacular Structures towards Earthquake**", in partial fulfilment of the requirement for the award of the degree of Master of Technology in Disaster Mitigation and Management, submitted in the Centre of Excellence in Disaster Mitigation and Management, Indian Institute Of Technology –Roorkee, is an authentic record of my own work carried out under the guidance of **Dr. Amita Sinvhal, Professor**, Department of Earthquake Engineering, Indian Institute of Technology Roorkee.

I have not plagiarized or submitted the same work for the award of any other degree. In case this undertaking is found incorrect, I accept that my degree may be unconditionally withdrawn.

Prashansa Dixit

Dated: 16/5/'16

Place: Roorkee

**(PRASHANSA DIXIT)**

Enrollment No. **14552007**

---

## CERTIFICATE

This is to certify that the above mentioned statement made by the candidate is correct to the best of my knowledge.

A. Sinvhal
6.5.16

**(Dr. AMITA SINVHAL)**

Professor

Department of Earthquake Engineering

Indian Institute of Technology, Roorkee

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# ABSTRACT

Vernacular structures are specific to a region and reflect the traditional wisdom of constructing houses using locally available materials and basic techniques. There exist some exceptional vernacular structures which have shown outstanding resilience during earthquakes in severe seismic zones. This gives a strong reason to study these earthquake resistant vernacular structures which have been saving lives of the occupants since a commendable span of time. Five vernacular structures, found on the plate boundary regions i.e severe seismic zone, are studied for their features which have made them resilient to earthquakes. These are: Bhunga houses of Gujarat, Ikra houses of Assam, Koti banal structures of Uttarakhand & Himachal, Dhajji Dewari of Kashmir and Nicobarese huts of Nicobar Islands.

The intrusion of modern construction practices even in the difficult locations, where these vernacular structures mostly exists, has overlooked these traditional practices and these structures are losing their real attribute. Modern interference and modification in design based on the experience from past earthquakes, affects the vulnerability of vernacular structures. The affect on vulnerability due to evolution in design of various building parameters is shown through an evolution-vulnerability index.

In further chapters, risk assessment of the Kangra seismogenic source zone is done by applying the methodology as per Arya (2013) and districts with highest risk are studied. Parameters used in assessing seismic risk were: building types and grade of damage, housing data, seismic zoning map of India (BIS: 1893- 2002), population of each district, and time of occurrence of the earthquake. This study indicates that Kangra and Mandi district would suffer maximum human casualty in terms of numbers and percentage respectively. Few of the susceptible areas in these districts are interpreted based on the physiography and human settlements, through satellite images. These areas might suffer damage due to hazards like landslides, rockfall, liquefaction etc. Being located in the regions through which MBT passes, lot of destruction is seen in past earthquakes but still modern construction is rushing in these terrains where the earthquake resistant vernacular structures have shown resilience and survived. Thus these practices need to be revived and lessons learnt from vernacular approach both at planning or settlement level and building level can form the basis for new developments coming up in such regions. Also there is a need to preserve the existing vernacular structures so that they can be examples for more years to come and should be promoted by initiatives of authorities concerned in disaster management.

# 1. Introduction

## 1.1 What is vernacular architecture?

It is the architecture style that is specific to a place or region. It reflects the local traditional designs and use of local construction material. Factors that mainly govern vernacular architecture of any place are climate, culture, economy, building techniques and history. Construction is usually done by the people themselves with their basic knowledge and experience. It is economical, energy efficient and sustainable form of architecture. Many construction practices that are centuries old are a proof that they have withstood many disasters and have great potential.

### What is resilience?

Resilience is the capacity of any system, which is potentially exposed to hazards, to adapt by resisting or changing in order to maintain an acceptable level of functioning. Also the system should be capable of organizing itself to increase the capacity for learning from past disasters, for better future protection and improved risk reduction measures. *(UN/ISDR. 2005)*

## 1.2 Seismic zoning of India and Vernacular structures

The high seismicity of India is the result of the plate tectonics. Indian plate shares all three types of boundaries with the neighbouring plate's i.e convergent, divergent and conservative.

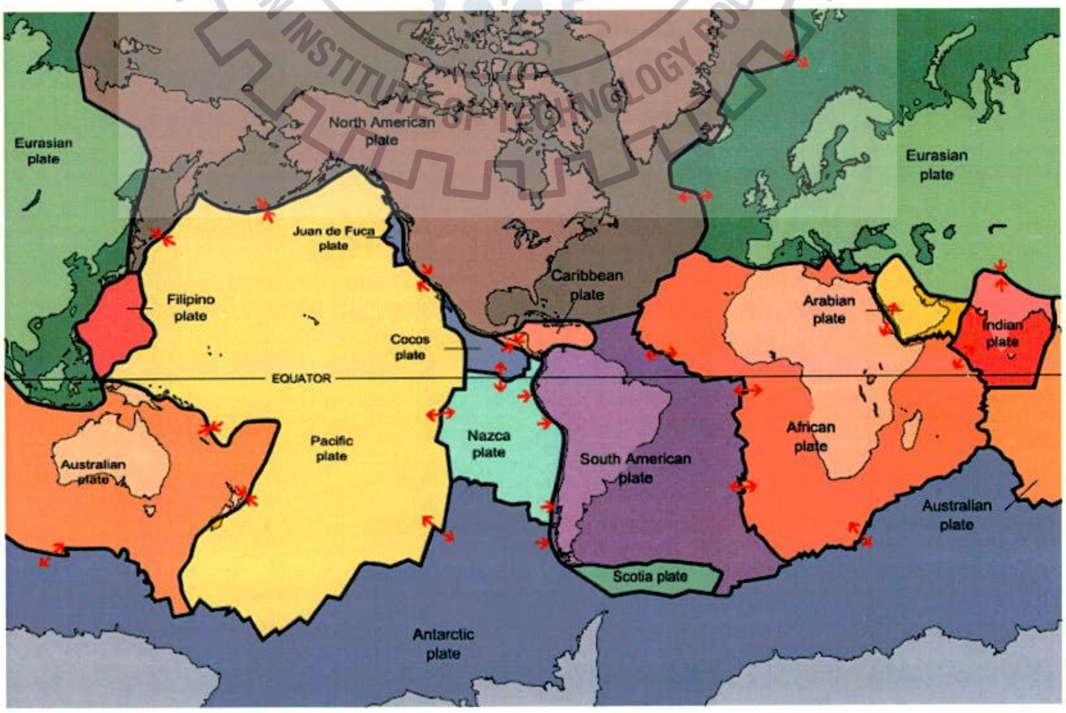



**Fig.1.1 Plate Tectonic Map of the world** *(Source: USGS)*

The convergent boundary between the Indian plate and the Eurasian plate, where the Indian plate is subducting below the Eurasian plate, has led to the formation of Himalayan arc which has high seismicity with western and eastern syntaxis having dense cluster of epicentres. Similarly in south, the island arc is formed due to subduction of Indian plate under the adjacent plate. Such activity has resulted in faulted regions and severe seismic zones which are frequently prone to earthquakes.

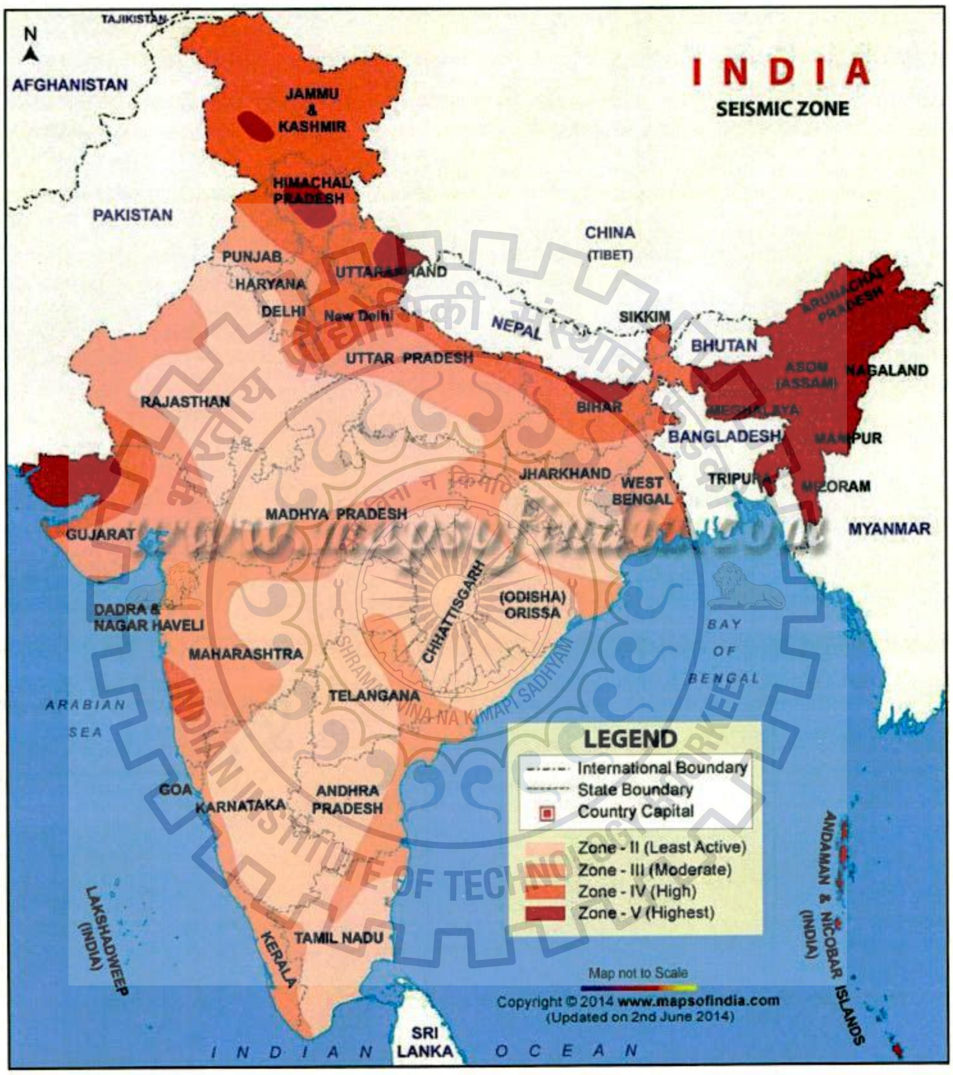
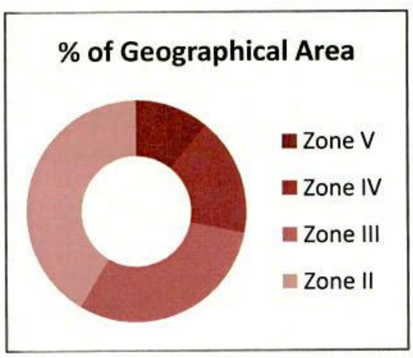



**Fig.1.2. Seismic Zoning Map of India** *(Source: mapsofindia.com)*

Around 59% of Indian land lies in the high seismic zone area i.e. zone III, IV & V *(NDMA-guidelines on management of earthquakes)*. Seismic zone V is the highest severity zone. The intensity of earthquakes *(as per MSK 64)* associated with this zone is IX and above. And it has zoning factor Z i.e. effective peak ground acceleration PGA which is 0.36g



based on intensity of shaking *(IS 1893-2002)*. But even the land under seismic zone V is inhabited by people. Their shelters have evolved through generations. They adopted themselves to the constraints and potentials of the place. In such areas exists some exemplary structures which have survived several past earthquakes without being influenced by the modern day construction techniques and just by using simple traditional knowledge and locally available materials. **Some examples of these earthquake resistant vernacular structures** are mentioned below:

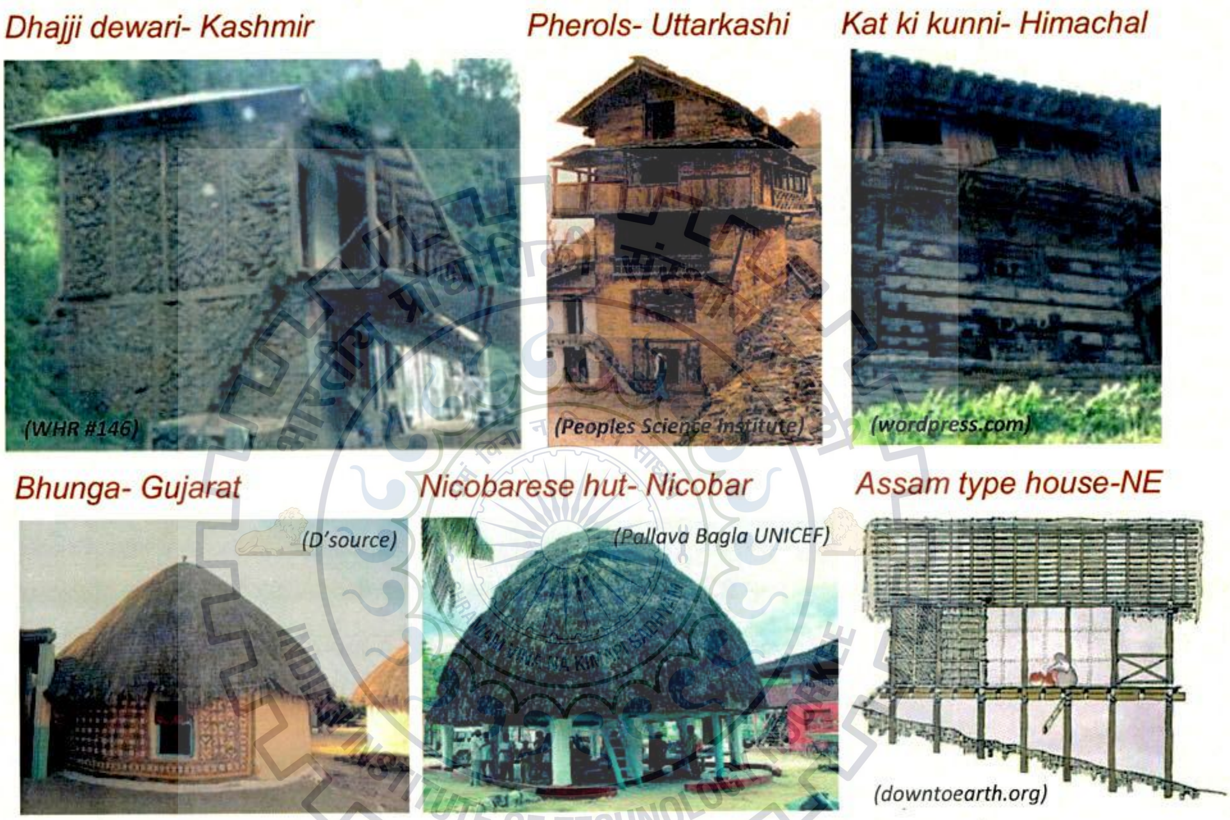



**Fig.1.3.Various earthquake resistant vernacular structures located at different high seismic zone areas**

## 1.3 Need of the study

Earthquake disasters accompany destruction of the habitats and human casualties. Gradually, people learnt to live with earthquakes. Their habitat evolved after repeated events of such disaster. Few vernacular styles have proved to be impressive earthquake resistant structures like the dhajji dewari of Kashmir. Many other vernacular structures have shown such resilience during disaster but as the world is embracing modern architecture, these traditional practices are lost. More life loss is because of the collapse of the house, than the earthquake itself. There is much to be learned from traditional knowledge and apply it in areas with adverse seismic conditions. It is thus necessary to study such vernacular structures, know the techniques imparting resilience to them and promote their construction in particular regions.

## 1.4 Objective

To study the earthquake resilient vernacular structures in different severe seismic regions and features that imparts resilience to them.

To identify the modifications/evolution in design of these structures those happened over time and prepare an evolution-vulnerability index.

To identify high risk area in a seismogenic source zone through risk assessment and suggest measures based on learnings from vernacular approach.

## 1.5 Methodology

Study is done on the general features of the selected vernacular structures, how they have evolved over time and according to need, what are the earthquake resilient features and their vulnerability is indicated in terms of more, less and least (i.e desirable feature) vulnerable depending upon the evolution or changes made in various parameters of these structures. With the help of this indicator, various combinations of building parameters can be made to know that what makes the building more or less vulnerable. Thus the effect of modification on the vulnerability of the structure can be seen.

Further the study of various seismic source zones (SSZ) is done and the SSZ that is most vulnerable to reoccurrence of a high magnitude earthquake is selected for risk assessment. A methodology is adopted for calculation of risk, which includes life loss during favourable and unfavourable time and also the number of building damage, in the districts lying under selected SSZ. District with highest level of risk is obtained that is further studied and mitigation measures in case of earthquake are given keeping in view the learning from the vernacular structures thus improving upon the resiliency.

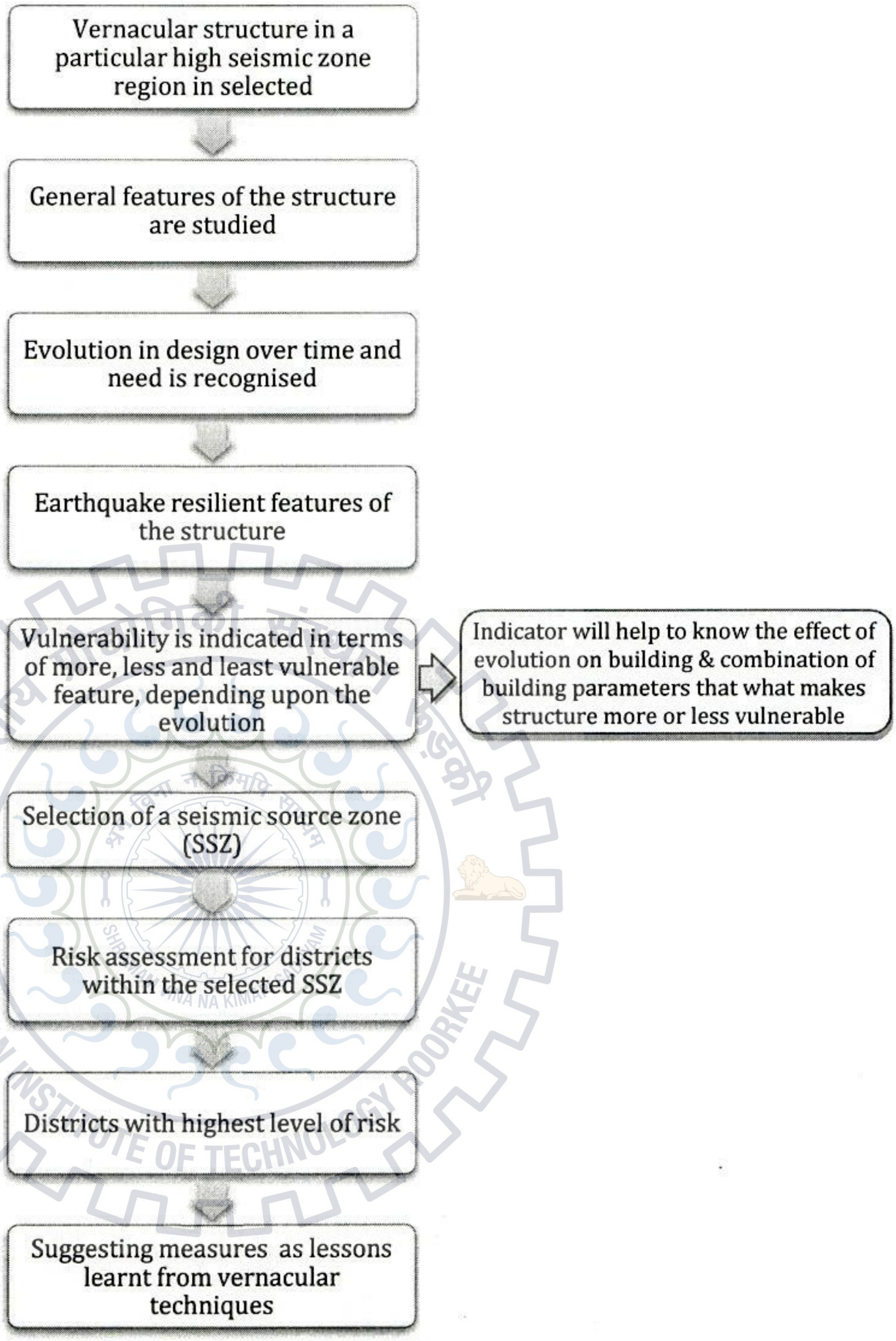



**Fig.1.4 Overview of study methodology**

# 2. Literature Review

Few of the vernacular structure are reviewed here, which have shown commendable performance during seismic activity. The structures have been analysed by different methods by researchers and the results prove their strength with which they stand firm during earthquake. Also the seismic source zones are reviewed for the risk assessment purpose.

## 2.1 A Vernacular Style of Kashmir & Himachal

The Kashmir earthquake that occurred on 8th October 2005, magnitude 7.6, devastated the Kashmir valley in India as well as Pakistan. The houses that survived the tremors were the old **dhajji dewari** houses in both rural and urban settings of Kashmir. These houses were the learning lessons and so after the disaster, more and more people implemented this technique for reconstruction instead of building stone wall houses that collapsed during the disaster. Also dhajji dewari structures were built in Mandi district of Himachal Pradesh after the devastating 1905 Kangra earthquake. Mainly the government buildings there were built in this style. This vernacular technique is around 200 years old and has evolved over this period to perform reasonably well during earthquakes. The style is generally found in western Himalayas.

### *2.1.1 Features of the dhajji dewari structure*

Dhajji dewari means 'patch work quilt wall'. It is also referred as 'brick nogged timber frame construction' in the Indian standard codes.

Diagonal bracing is the important feature of this type of construction. It gives resistance against the shear forces and provides triangular stability to the walls. Also the bracing helps in confining the cracks.

The structure frame and the loose infill plays important role in absorbing the energy through friction. These flexible structures are lightweight as the frame helps in reducing the thickness of walls and also the roof is made of light material.

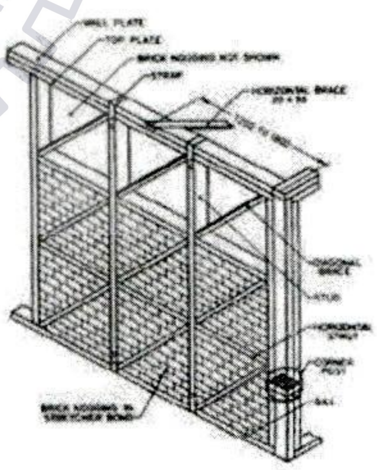
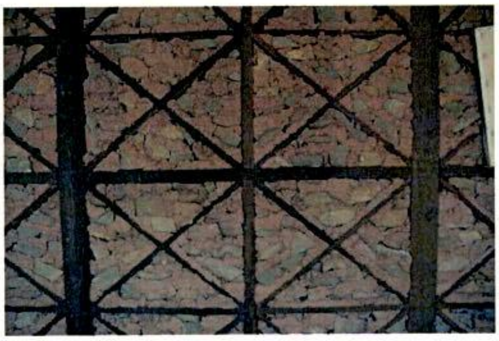
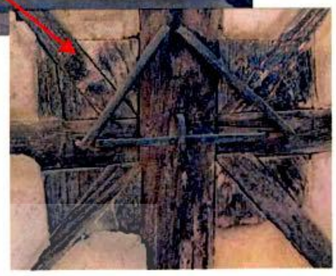


**Fig.2.1. Sketch of a dhajji wall from Indian Building Code IS-4326**



A)

B)



C)

**Fig.2.2. A) Dhajji dewari building in Kashmir**
*(Source: World Housing Encyclopedia #146)*
**B) Dhajji dewari building in Dharamshala,H.P**
**C) Detailing of bracing connection to the frame by iron pins**
*(Source: R.Das, People's Science Institute)*

### *2.1.2 Structural Analysis of a Dhajji Dewari Model*

The dhajji dewari house of the type constructed after the earthquake of Kashmir 2005 was modelled, in a research paper *"Seismic Performance of Dhajji Dewari.", Hicyilmaz, K., et al.*, for the analysis of its seismic performance in future cases of disaster.

Following considerations were taken into account:

- The timber frame and the masonry were modelled as the solid elements. The contact surfaces between all these elements and the joints accounted for the frictional behaviour.
- The light weight roof system was idealized.
- Connections between the frame members were made nailed connections.
- Timber was assumed as elastic material and masonry infill as incompressible.
- Roofing system did not include horizontal diaphragm bracing, as typically this is not the design feature of these buildings.

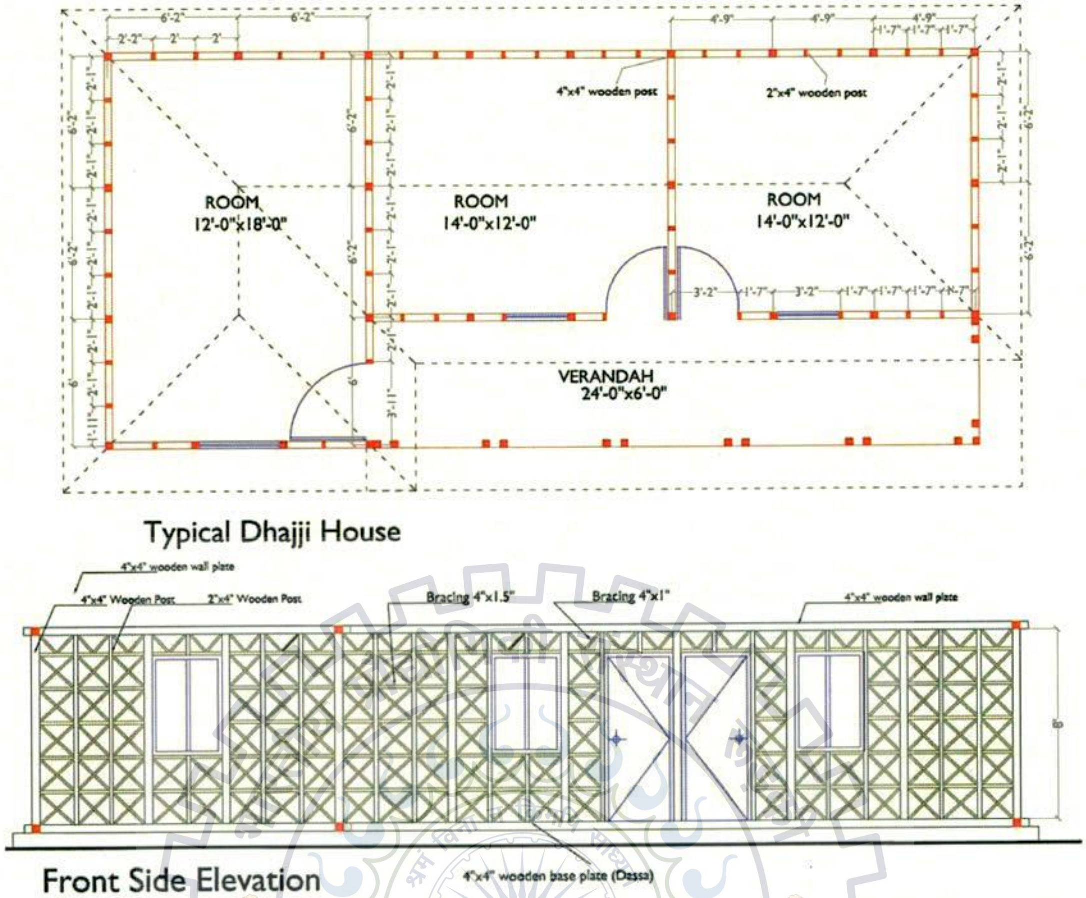



**Fig.2.3. Drawings of a typical dhajji dewari house, built post 2005 kashmir earthquake**
*(Source: Hicyilmaz, K., et al. 2012)*

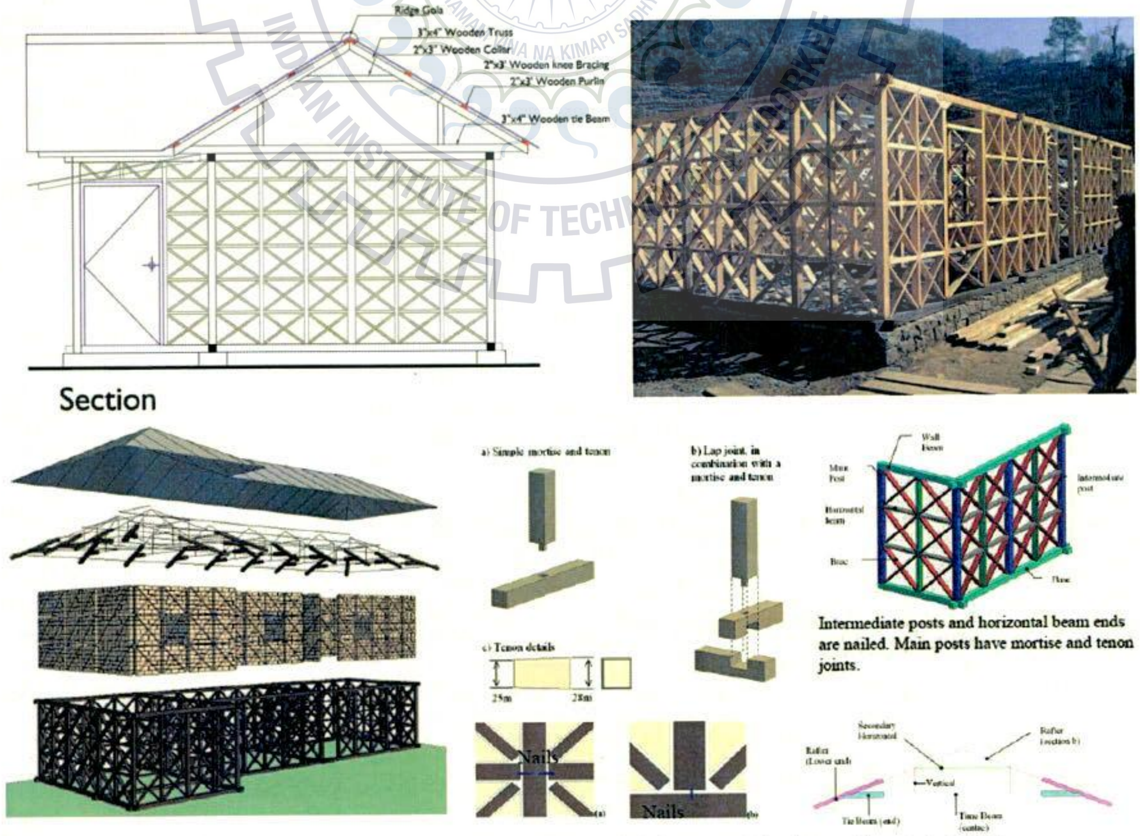



**Fig.2.4. Exploded view of dhajji dewari model** *(Source: Hicyilmaz, K., et al. 2012)*

Two types of model were analysed, one with nailed connections and other without nails. It was found that the model without nails underwent out of plane failure of the short walls. Failure was initiated as the infill at the top of the walls knocked out. The structure without nails becomes more flexible and has longer period of vibration thus attracting lower accelerations also from the earthquake. The model with nailed connection gave good performance result. Nails helped in keeping the timber framework together, thus minor damages happened.

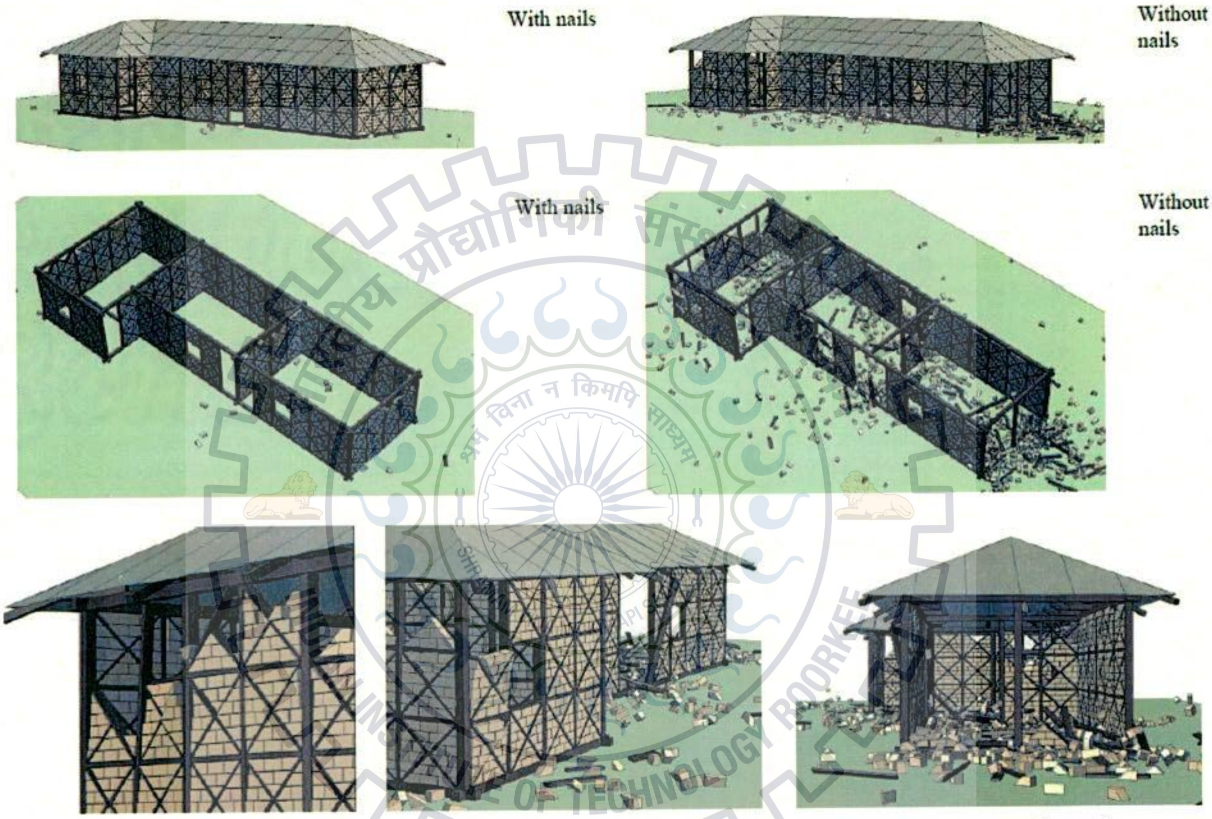



**Fig.2.5. Graphical presentation of the building response** *(Source: Hicyilmaz, K., et al. 2012)*

## *2.1.3 Inferences*

- Proper construction of these structures and their maintenance can safely resist earthquake in high seismic zones.
- The timber framework provides proper confinement to the masonry infill, as long as the frame is intact. Therefore timber connections are important and their detailing should be done for proper strength and ductility. Strategic use of nails/metal straps can improve the building performance.
- The seismic energy gets dissipated through friction between the infill panel and the framework and within the yielding of the connections.

- Energy absorption capacity of the building increases with increase in overburden level acting on the masonry. Thus even two to four storey structures also performs well.
- Shortening the braces so that they disengage from the timber frame can also nominally improve the seismic energy absorption. There were no adverse effects observed by doing so. This will reduce the timber volume, helping in preserving the natural resources.

### *2.1.4 Comparison*

| Dhajji dewari construction | Confined masonry construction |
|---|---|
| Mud mortar is weak and starts yielding even under small lateral loads | Cement sand mortar used to bond the masonry is brittle and stiff |
| Infill masonry panel size is small which is advantageous as the cracks cannot propagate further | Infill masonry panel size is large and if crack occurs it continues to a long distance. |
| Energy dissipated through friction | Energy dissipated through deformation of frame members |
| Limited and repairable damage | Much damage that generally has to be replaced, thus costly |

## 2.2 Bamboo or Ikra houses of North-east

The simple and non-engineered bamboo houses are common traditional housing typology throughout Northeast India. These light weight structures embrace the basic ideas of earthquake resistance construction. They have proven their strength during past earthquakes and thus, are still under practice.

The superstructure is made of bamboo framework that is connected to the foundation masonry wall 1m above the plinth. The framework is filled with ikra grass and complete wall is covered with mud plaster. The roof is also made of bamboo truss and covered with thatch or sheeting.

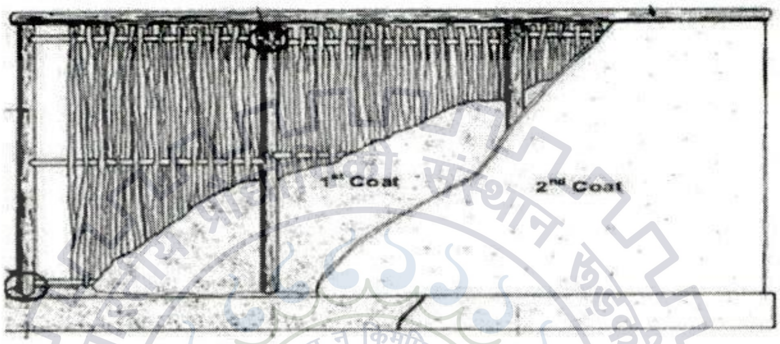



**Fig.2.6. Ikra wall elevation** *(Source: Maulik D.K et al. 2011)*

### *2.2.1 Comparison of Ikra with modern construction practices through model*

In a research paper, *"Comparative study of bamboo (ikra) housing system with modern construction practices." by Maulik D. K. and C. S. Sanghvi,* the ikara and the modern reinforced & confined masonry system are modelled and simulations are carried out in software.

Ikara is modelled in software based on a school building near Dispur in Assam. Bamboo that is the main structural member is configured as per INBAR (international network for bamboo and rattan). Two models are taken for modern construction practice. One is reinforced brick masonry system in which the reinforcement configuration is taken as per draft IS 1905(IITK-GSDMA). Second is the confined brick masonry system, the tie beam and column configuration is taken as per the EERI (seismic design guide for confined masonry-2011). All three models have same plan dimension.

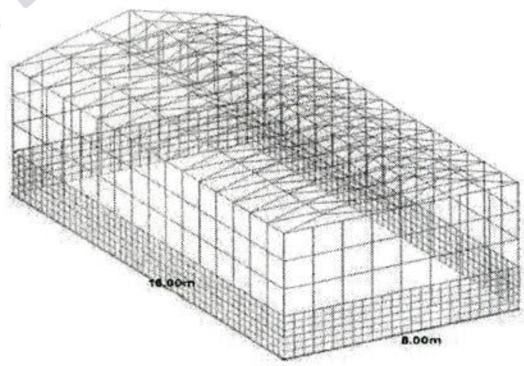



**Fig.2.7A. Ikara (Bamboo) model**

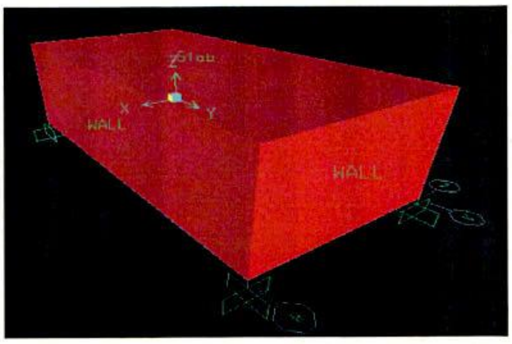



**Fig.2.7B. Reinforced brick masonry model**

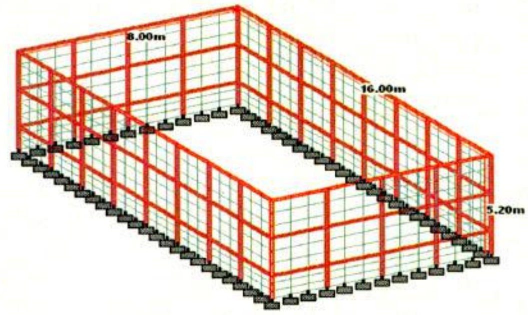



**Fig.2.7C. Confined brick masonry model**

### *2.2.2 Results of model analysis*

- Bamboo is a flexible material and offers less critical damping so the frequency of bamboo housing becomes less as compared to other two systems.

- When seismic mass of these structures is worked out, seismic force on different systems is as follows, which is least in ikra housing.

| Housing system | Seismic force on different housing system. kN |
|---|---|
| Bamboo housing ( Ikra housing ) | **14.55** |
| Reinforced brick masonry system | **112.00** |
| Confined brick masonry system | **124.13** |

*(Source: Maulik D.K et al. 2011)*

- Through surface generation in software, stress concentration is studied in all three systems

**Fig.2.8. View of stresses in all three types of system model**
*(Source: Maulik D.K et al. 2011)*

The stresses generated in bamboo (ikra) housing system are higher than the other modern housing system. Thus the material used in ikra housing system is properly utilised.

- In ikra housing system, bamboo is the main structural member which is a ductile material. Hence, during an earthquake event its performance is improved.

## 2.3 Vernacular style of western-central Himalayas

Kath ki kunni structures found mainly in Kullu, Mandi, Shimla and Solan district of Himachal Pradesh and the Pherols of Uttarkkashi bear close similarity with each other. Thus these are classified under same architecture school called Koti Banal architecture. The name koti banal is derived from the koti banal village of Uttarkashi where multi storied traditional structures of this peculiar style are seen.

### *2.3.1 Resilient features*

The structures under this style are found to be centuries old which proves that they have witnessed many earthquake events without being damaged. The prominent features that make this type of construction earthquake resistant are:

1. **Timber tie-bands:** A pair of parallel wooden beams runs along the entire length of the walls at regular intervals and in alternate direction. The alternate pair is kept perpendicular to each other. The spaces between these wooden beams are filled with well-dressed stone masonry. These beams thus act as tie bands and hold the superstructure, resisting tension and lateral forces.

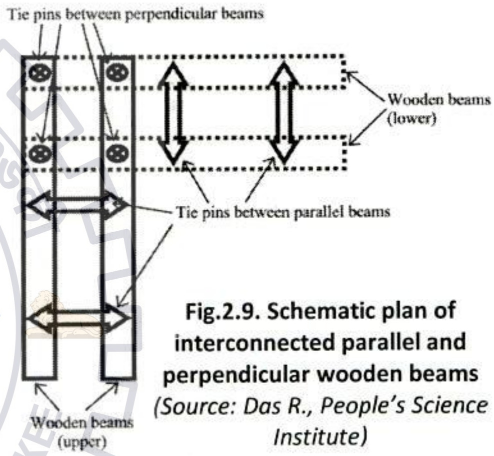



**Fig.2.9. Schematic plan of interconnected parallel and perpendicular wooden beams** *(Source: Das R., People's Science Institute)*

2. **Interconnections:** The parallel pair of timber beams is interconnected at regular intervals along the length of the wall with wooden pegs. The perpendicular pairs of beams are interconnected at the corners vertically as shown in (Fig.2.9). Thus the corners are reinforced and strengthened and prevent the wall from splitting under high compression forces.

3. **Openings:** Openings are kept small and are framed with heavy reinforcing timber. Heavy framing helps in coping up with the stress developed due to opening during earthquake. Also the openings are not placed in vertical alignment which otherwise weakens the wall.

### *2.3.2 Equivalent static lateral force analysis*

In a research paper *"Earthquake-safe Koti Banal architecture of Uttarakhand, India." by Piyoosh Rautela and Girish Chandra Joshi*, equivalent lateral force analysis of a five storied koti banal structure (as shown in Fig. 2.10) is done. Lateral forces on a structure are generated due to its mass during an earthquake.

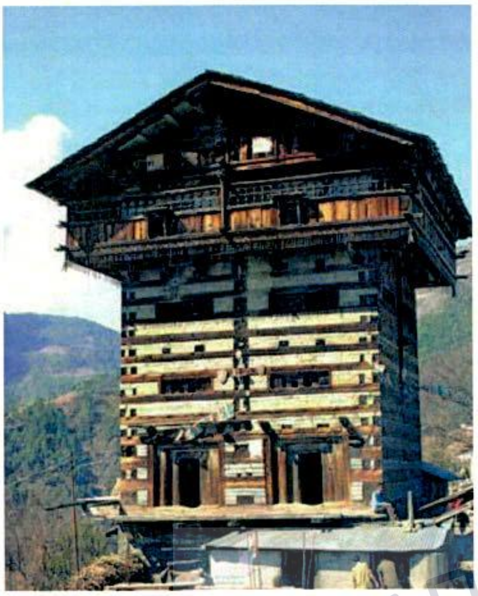


**Fig.2.10. Five storied structure in Koti Banal village constructed 880 ± 90 yrs BP** *(Source: Rautela P.)*

For this analysis, the methodology is adopted as per IS1893 (Part 1):2002. To transfer the seismic forces to the ground, a building should have continuous load path. In case of Koti banal structures the earthquake forces generated in all the building elements are delivered through transverse walls which get bent between the floors. From the transverse walls, lateral loads move to the side shear walls by horizontal floor and roof diaphragm. From diaphragms forces are distributed to vertical resisting components which transfer these forces to the foundation.

## *2.3.3 Inferences*

Floors of Koti Banal structure are made of 20–22 mm thick wooden planks are expected to have high degree of flexibility and all the walls are 45 cm dry dressed stone that are highly rigid. These factors adequately fulfil the flexible diaphragm conditions.

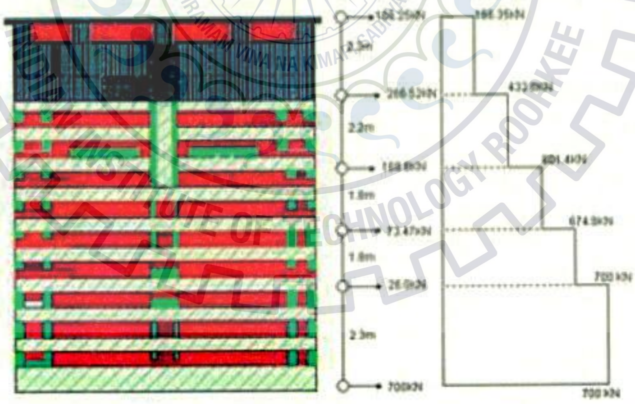



**Fig.2.11. Side elevation & lateral force distribution in different stories of Koti Banal structure as shown in Fig. 2.10** *(Source: Rautela P.)*

Based on the result of equivalent static analysis, the design base shear for Koti Banal structure is computed to be 700 kN, that works out to be 23% of total seismic weight of the building.

These age-old structures are still intact and their non-structural components have not been damaged during earthquakes, despite being located in the most severe zone of risk (zone V). The age of these structures clearly shows that they would have experienced at least design basis earthquake (DBE) ground-shaking in their lifespan.

Apart from the resilient features these stable structures were also made to adapt to the agrarian lifestyle of the traditional people. Upper storeys were used as living spaces because these are the warmer areas allowing sunlight and rising warmth from the livestock kept in lower storeys. To avoid the danger of wild animals also, people stayed on upper storeys, thus keeping in mind the safety factor. Thick walls and heavy roofs are cold climate responsive features in these structures as thick walls provide good insulation from cold and sloping roof carry the weight of snow.

It is also seen that many of these old structures are being put to disuse and are in deteriorating condition due to the lack of maintenance. People are demolishing these structures so as to use the disassembled material for the construction of new modern style dwellings. These structures should thus be protected as heritage structures.

## 2.4 Kangra Seismic Source Zone

Himalayan arc is the most seismically active region in India due to continental collision. Focusing on the Western Himalayas, as the part of active Alpine Himalayan belt, in this region nine Seismogenic Source Zones (SSZ) have been identified by *Mridula et al (2014)*, based on the vicinity of MBT and MCT which includes state of Himachal Pradesh, Uttarakhand, Jammu & Kashmir.

SSZ is an area demarcated on the basis of the density of seismicity cluster and tectonic elements around them. Thus every source zone has a dense cluster of earthquakes and is marked by important tectonic feature. The nine source zones are: Kangra SSZ, Uttarakhand SSZ, Western Syntaxes SSZ, Kaurik SSZ, Kashmir SSZ, Western Tibet SSZ, Karakoram SSZ, Jhelum SSZ, Indo Gangetic SSZ.

**Kangra SSZ** is demarcated by MCT in north, MBT in south, Kishtwar fault in west and Sundarnagar fault in east. The magnitude 8.0 great Kangra earthquake is a part of this zone.

**Uttarakhand SSZ** is demarcated by MCT in north, MBT in south, Sundarnagar Fault in west and 80 ° E longitudes in east. Magnitude 6.8 Uttarkashi and 6.7 Chamoli earthquakes are part of this zone.

**Western Syntaxes** SSZ is marked by Main Mantle Thrust (MMT) and MBT. The 2005 Kashmir earthquake ($M_w$=7.2) is a part of this zone. This zone has maximum earthquakes as compared to others.

**Kaurik SSZ** is demarcated by MCT in south, Karakoram fault in north, Tso Morari fault in western extremity and Kaurik fault in the east. The 1975 Kinnaur earthquake ($M_w$=6.6) is a part of this zone.

**Kashmir SSZ** is demarcated by MCT in south, Shyok suture in north, northward, Kishtwar fault in west, and Tso Morari Fault in the east. This zone shows sparse seismicity.

**Western Tibet SSZ** is demarcated by MCT in south, Karakoram fault in north, longitude 80° in East and SSZ 4 in on the western boundary. This zone has least number of earthquakes.

**Karakoram SSZ** is demarcated by the Shyok suture in south, 36°N latitude in north, SSZ 3 (western syntaxes) on the west, and 80° E latitude in east.

**Jhelum SSZ** has a strike slip Jhelum fault trending in north south direction. It is the smallest source zone.

**Indo Gangetic SSZ** is the largest source zone but shows scanty seismicity.

For all these source zones, PSHA (Probabilistic Seismic Hazard Assessment) is done in terms of PGA for probability of exceedance of 10% and 2% in 50 years for a return period of 475 and 2475 years, respectively.

The result of this research helps in identifying the source zone which is most vulnerable in terms of PGA, return period and magnitude. Kangra SSZ is found to be most vulnerable followed by Kaurik and Syntaxes SSZ and then Uttarakhand SSZ.

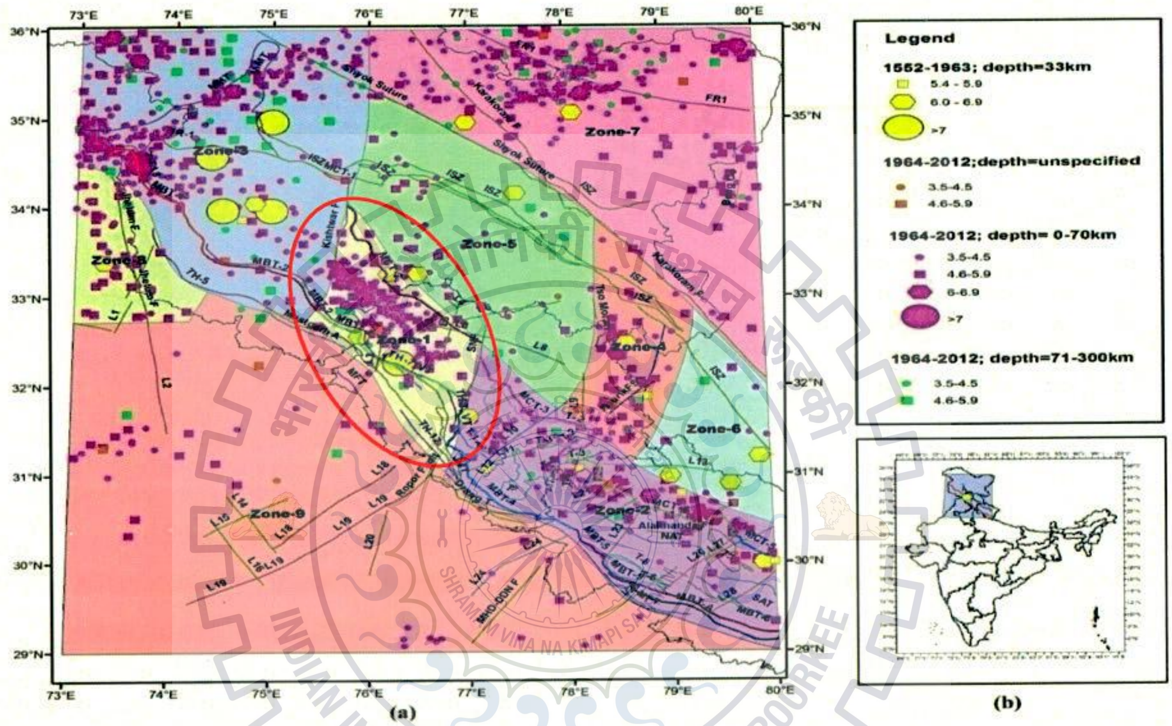



**Fig.2.12. a) Seismogenic Source Zones with Seismo-tectonics, encircled is the Kangra SSZ**
**b) Map of India showing MBT, MCT and EPICENTRE OF Kangra earthquake**
*(Source: Mridula, et al. 2014)*

# 3. Study of Vernacular Structures

In this part of the dissertation, study on the selected earthquake resilient vernacular structures is done. These structures are located in high seismic zone areas formed due to activity at plate boundary and still have shown resilience even after facing many earthquakes. These are example of traditional construction carried out till date because of their firmness during earthquakes.

General features of these structures are studied, the evolution/modification they underwent through time and according to need and the earthquake resilient features of these structures. This helped in forming a vulnerability index for each type of structure depending upon the changes in structures. Changes or evolution depends upon the availability of materials, construction techniques, comfort of the occupants, etc. But these changes can adversely affect the behaviour of the structure during earthquake i.e. either the change can make the structure resilient or weak. Thus the vulnerability index gives an idea about the strength. The vulnerability on the index is indicated in terms of more, less and least. Building parameter having least indicator of vulnerability becomes the desirable feature of the structure and vice-versa. Thus with the help of this indicator various combinations of building parameters can be made to know that what makes the building more or less vulnerable and also the effect of modification on the vulnerability of the structure can be seen.

Five vernacular structures from different states of India, in high seismic zones and almost at the plate boundary, are selected.

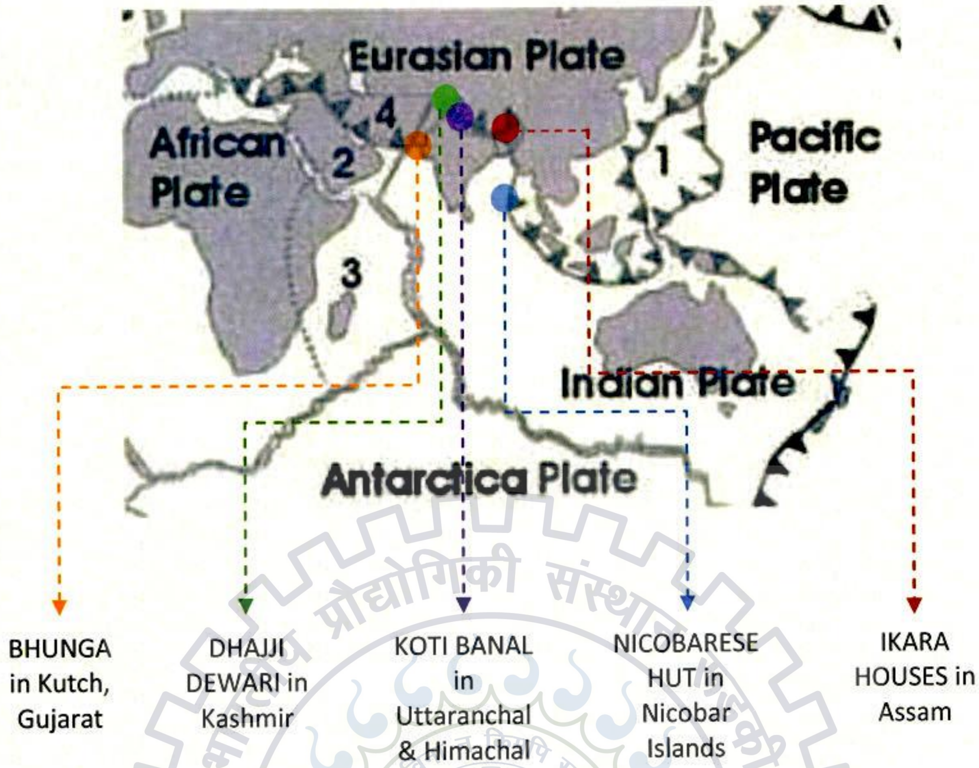



**Fig.3.1 Tectonic plates around India marked with the location of five vernacular structures**

*(Image Source: Sinvhal A. Understanding Earthquake Disasters 2010)*

## 3.1 BHUNGA houses in Kutch, Gujarat

Bhunga houses are mainly found in northern parts of kutch region- specially Banni and Ludia village. As these traditional houses are derived from the locally available material, the Banni region has silty clay soil type which probably led to construction of mud and thatch houses. Similarly, the Ludia region has ample limestone which led to its use in walls of bhunga and uncoursed rubble masonry for foundation. These houses survived in the bhuj earthquake of 2001 (M 7.7) while many modern buildings were razed to ground even being quite far away from the epicentre like the buildings in the cities of Ahemdabad and Surat.


A) Map showing bhuj earthquake, 2001

B) Traditional Bhonga that survived in Ludia village (≈70 km N of epicentre)

Modern construction that collapsed in Ahemdabad (250 km E of epicentre)

**Fig.3.2. A) Map showing bhuj earthquake of 2001**
**B) Effect of earthquake on buildings at different distances from epicentre**

A study on the earthquake affected structures in the Ludiya village shows the commendable performance of the bhunga houses over other type of houses. Maximum numbers of bhunga houses were in liveable condition as compared to other type of houses.

| Type of house | Bhungas | Kaccha | Pucca | Kuccha-Pucca |
|---|---|---|---|---|
| Totally destroyed | 5 | 50 | 36 | 13 |
| Irrepairably damaged | 7 | 41 | 30 | 22 |
| Repairably damaged | 13 | 17 | 13 | 16 |
| Little damage | 3 | 1 | 45 | 4 |
| No damage | 8 | 2 | 0 | 1 |
| Total | 31 | 111 | 84 | 56 |

*(Source: Vastu-Shilpa Foundation)*

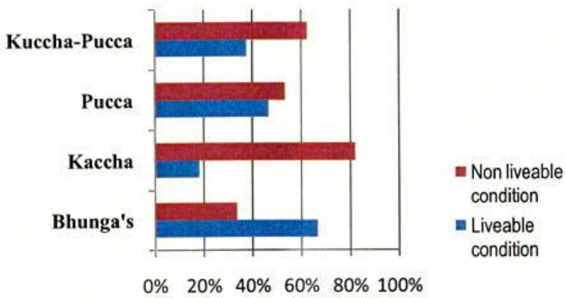



**Fig.3.3. Cluster layout of bhungas in Ludia village before 2001 earthquake**

### *3.1.1 General features of the structures*

- Bhungas are circular in plan and cylindrical in volume. Inner diameter ranges from 3 to 6 meters.

**Fig.3.4. A typical bhunga house** *(World Housing Report #72)*

- These are simple mud wall and thatch roof structures.
- The roof is conical in shape and supported on bamboo frame and single vertical post.
- Very few and small openings in order to be climate responsive.

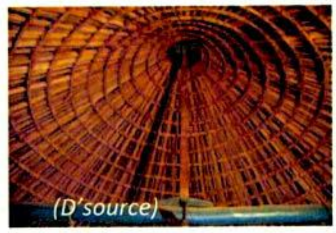



**Fig.3.4. Conical roof of a typical bhunga house**

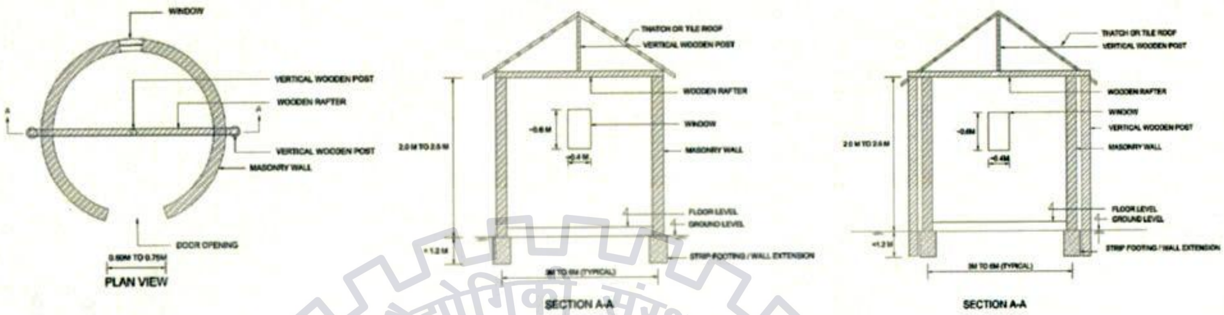



**Fig.3.5. Plan and section of a typical Bhunga house** *(Source: World Housing Report #72)*

### 3.1.2 *Design evolution*

- With time adobe wall construction evolved to stone or burnt brick masonry and bamboo reinforced wall construction in mud or cement mortar.
- Design evolved from light weight conical thatch roof material to use of mangalore tiles.
- Construction of circular strip foundation instead of extending wall below the ground.
- Many a times, roof is supported on wooden posts outside bhunga instead of directly resting on the walls.

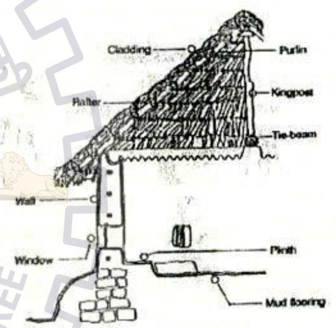



**Fig.3.6. Cross section of an evolved Bhunga house**
*(Source: Apurva Amin,CEPT)*

### 3.1.3 *Earthquake resistant features*

- Because of the circular shape, all the lateral forces are resisted through shell action.
- Small openings do not hinder the lateral forces path.
- Thick walls provide high in plane stiffness.
- Low slenderness ratio increases the stability of the structure.
- Light weight roof develops less inertial forces.
- In case roof is supported on wooden posts outside bhunga, the resistance of roof further increases.

### *3.1.4 Evolution and Vulnerability Index*

**Site:** Flat terrain
**Design:** Robust circular design

<u>Roof</u>

Supported on walls
On vertical posts

<u>Foundation</u>

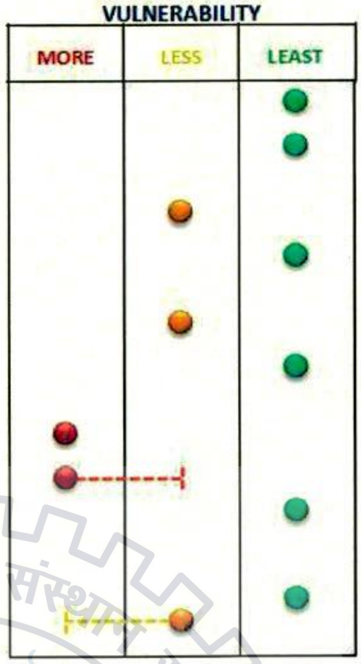
Wall extended below ground
Strip foundation

**Material:** <u>Walls</u>

Plant, mud, husk
Adobe with mud mortar
Stone/burnt brick in cement mortar

<u>Roof</u>

Thatch bamboo/grass
Heavy tiles



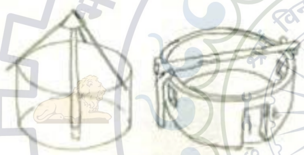



**Fig.3.7. Structural variation in construction of Bhunga house**

*(Choudhary et. Al 2002)*

**Fig.3.8. Collapse of adobe wall Bhunga houses**

## 3.2 Ikra houses, Assam

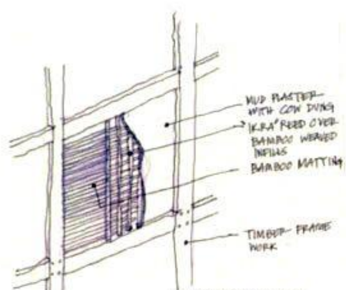
North-eastern part of India is one of the most active seismic regions in the world. Some of the great earthquakes that have happened are Assam earthquake of 1897 (M 8.7), Assam-Tibet earthquake of 1950 (M 8.6) and Sikkim earthquake of 2011 (M 6.9).

The Assam type construction style was started by Britishers and houses of this style were built in Assam and few neighbouring states during British rule. The old built structures can still be seen in urban areas which mainly consist of government and public buildings. Though this construction is now mainly practiced in rural areas. This construction style is also known as Ikra houses because of the use of reed in the construction. This reed has some special properties because of which it found its use in construction like: Grows in river plains and lake and is thus easily available, Less susceptible to insect attack: made of starch and cellulose, Bonds well with mortar, has Hollow inner core that provides good thermal insulation and does not shrink or flatten while drying.

**Fig.3.9. A school building in Assam made in Assam/Ikara style**
*(Source: World Housing Report #154)*

### 3.2.1 *General features of the structures*

- Conventional timber based houses.
- Generally single storey but two-storey structures can also be seen.
- The house is built on a plinth so as avoid the problems during rainy season.
- Wall frame is made by bamboo posts and the infill is prepared by vertically placing the ikra reed on the horizontal split bamboo matting. It is then covered by mud-dung plaster on both sides.
- Roof is made of wooden truss covered by ikra reed.




*(N. Subhakar, G.Amol)*

**Fig.3.10. Ikara wall panel**

- Commonly the plan shape is regular/rectangular for small family and may vary to L or C shape for multi-family house.

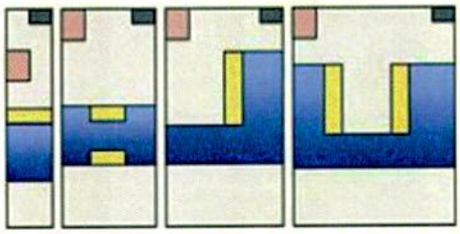



**Fig.3.11. Different plan type with important house areas**

- When constructed on a slope terrain, the access is from hillside and verandah is given facing the valley.
- High pitched roof is constructed so as to cope up with the heavy rainfall months. Slope depends on the material of the roof i.e if reed is used as roofing material then the slope is steep so as to drain off all the rain water but if other material like corrugated sheet is used then slope is less.
- Kitchen is made outside the house so as to avoid fire incidents as it is timber based construction.

### 3.2.2 *Design evolution*

- Prime building materials used for this construction are bamboo, reed and binder. But at some places mix of modern material is seen. Figure.3.11 Shows a house, in south Sikkim (Lingdum <100 km from epicentre) ,whose first storey is made of Ikara wall casted over with RCC slab and second storey is made of heavy unreinforced masonry wall with light corrugated sheets on the roof.

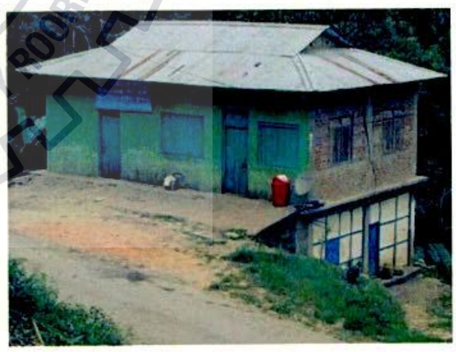


**Fig.3.12. House in Sikkim, mixed construction of Ikara and URM**
*(Source: World Housing Report #154)*

  Although no damage was seen to this house during 2011 earthquake but this practice can be dangerous.

- In rural areas, the bamboo posts are directly inserted in the ground (600-900mm). While in urban areas, the timber posts are supported on masonry/concrete pillars constructed up to plinth level and connected through steel bolts or clamps.

- Use of proper joinery methods instead of tying the members with cane ropes.

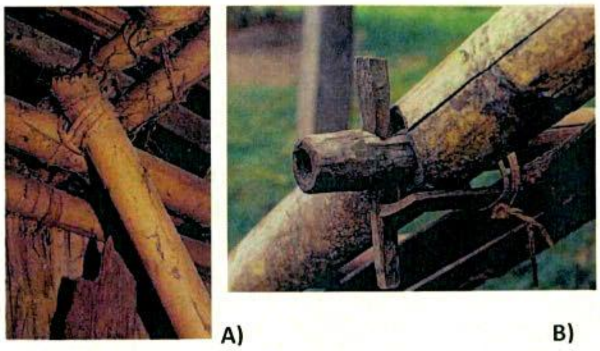


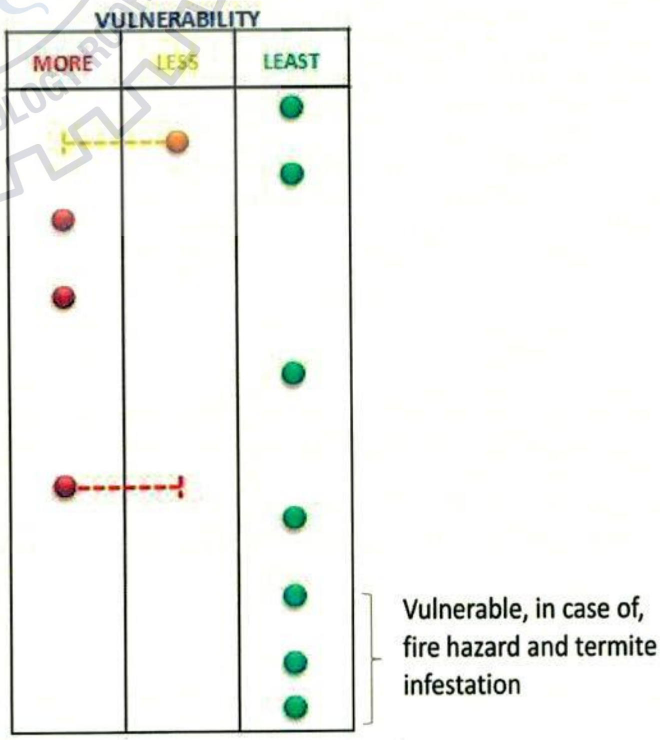

**Fig.3.13. A) Joining with coir ropes**
**B) Dowel and Tenon joint in bamboo**
*(Source: A+D magazine)*

### *3.2.3 Earthquake resistant features*

- Good planning, small openings (usually at the centre of the wall) and small overhangs/projection.
- The wall panels and the roof (ikra panels) reduce the overall mass of the structure. Falling of light debris has reported no injury in last earthquake.
- The connection between the wooden frame and the wall panels and the roof is good (through nails/bolts/straps in formal const.). Good connection and flexibility of the materials increases the resistance during earthquake.

### *3.2.4 Evolution and Vulnerability Index*

**Site:** Flat terrain
Slope/hilly terrain
**Design:** Regular Plan
More than one storey
<u>Foundation</u>
Vertical post directly inserted in ground
Post connected to masonry/ concrete pillar
<u>Connections b/w various members</u>
Coir ropes
Jointing/Nailing/bolting
**Material:** <u>Walls</u>
Bamboo/Timber & Ikara
<u>Roof</u>
Thatch Ikra
CGI sheet



## 3.3 Koti Banal architecture of Uttarakhand & Himachal Pradesh

The name of this architectural style is based on the name of 'Koti banal' village in Rajgarh area in Uttarkashi district of Uttarakhand where many buildings of distinct construction style are found. The Kat ki kunni houses of Kullu valley, Himachal and Pherols of Garhwal, Uttarkashi lie under the architectural school of Koti Banal. Despite experiencing many earthquakes such ornate multi storied houses are still common in these regions.

**Fig.3.14. Traditional house in Koti- banal village** *(Source: Rautela P.)*

These structures have survived major earthquakes like: 1803 Garhwal (*M 8.0)*, 1905 Kangra (*M 7.8)*, 1991 Garhwal *(M 6.8)*, and 1999 Chamoli (*M 6.8)*.

These structures have evolved as early as 1000 years BP.

### *3.3.1 General features of the structures*

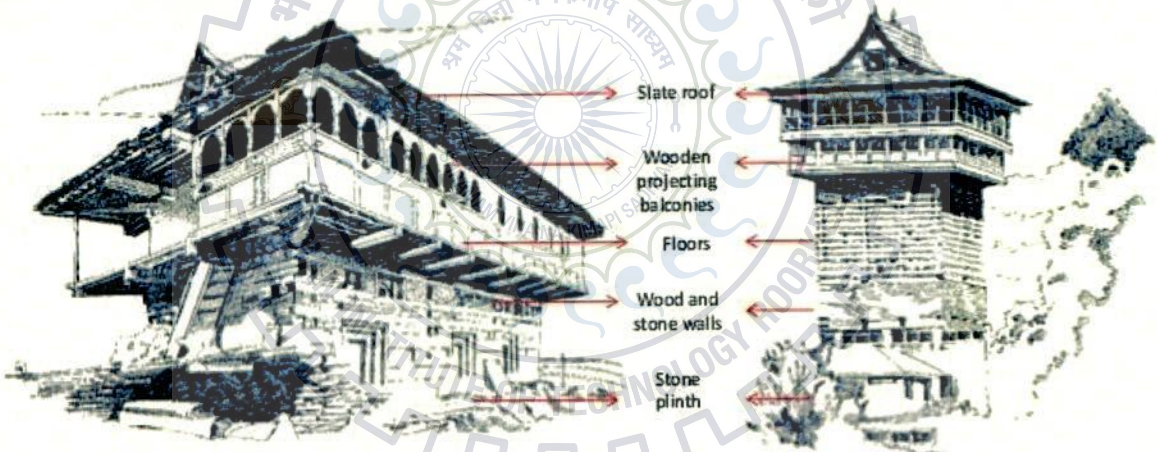
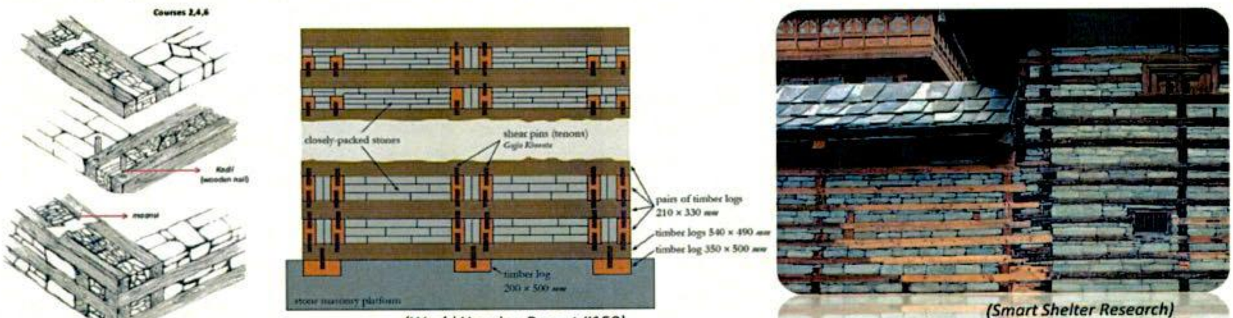



**Fig.3.15. Important parts of Koti banal structure** *(Source: Slideshare.net)*

- Structures are made using mix of wooden beams and stones placed in an alternate style.
- Rectangular plan configuration and dimension ratio varies between 1:1 and 1:4.
- Multi storied structures usually 4 to 5 storeys. Height usually 5m to 7m and is restricted to double the length of shorter side.
- Internal walls exist only in two units building separating main living area at each level
- The upper floors have additional wooden balcony, supported on cantilevered wooden logs of the floor system. This gives a false appearance of the structure to be heavy at top and unstable.

- The foundation trench is made of field and rubble stones, which is elevated as platform for the super structure. (Height of stone platform 2m to 4m)
- Wall construction is done as shown in the figures below:




(World Housing Report #150) (Smart Shelter Research)

**Fig.3.16. Construction of timber and stone wall**

- The alternate timber members are connected at the corners by wooden pins.
- The wooden cribbage structure is not formed at the upper parts of the wall where the dressed stones have a load-bearing function.
- The structure is reinforced by providing beams that run from middle of the wall from one side to another.
- Walls parallel to the floor beams are supported by large timber log, having holes at the two ends. A vertical shear key is inserted into the hole which provides support to the walls in out-of-plane direction.

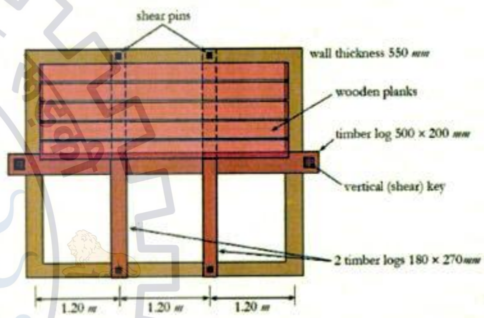



**Fig.3.17. Floor structure**
*(Source: World Housing Report#150)*

**Fig.3.18. Small openings** *(Source: World Housing Report #150)*

- Single entry and the openings are relatively small, well framed by wooden elements. There are no windows in the ground floor.
- Roof is wooden frame furnished with slate tiles.

### 3.3.2 Design evolution

- Evolution in design mainly started due to the comfort of the inhabitants.
- Increase in size of doors and windows for better ventilation and comfort.
- Variation in the internal walls layout at every floor and increase in the height of roof.
- From closely arranged timber logs to increase in distance between the logs filled with stone.
- Additional external verandah, supported on massive column for extra living space.
- Provision of vertical shear key outside the structure.

A)
B)

**Fig.3.19. A) Increase in distance between timber logs**
**B) Provision of additional verandah**
*(Source: World Housing Report #150)*

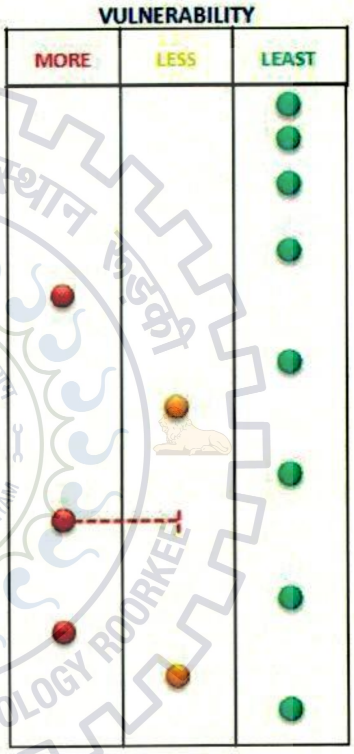
### 3.3.3 Earthquake resistant features

- Massive strong base of the structure helps in keeping the centre of gravity and mass in close proximity with the ground. This minimizes the overturning effect.
- Strong wooden empanelment around all the openings compensates for the loss of strength (happened due to openings).
- Timber beams running alternately all around the perimeter of the house act as tie bands which resist tension and lateral forces.
- The perpendicular pairs of beams are interconnected vertically at four points at the corners. Thus structure is tied vertically as well as laterally. The corners are strengthen and distributing the load vertically. The rigidity at the cross ways provide resistance against deformation and splitting under high compressive force.

- The thick wooden beam sections (ratio of length to width 2:3) are larger than that needed for adequate safety, thus increasing shock resistance.
- Dry stone masonry used has long and flat stones that distribute the vertical compressive load evenly and also prevent outward movement of the stones. Flexibility is provided during shaking as no rigid mortar is used between stones.
- Out of plane failure is controlled through vertical shear keys outside the structure.
- Larger upper storey dimension is compensated by using more wood and less stones as wood is lighter than stones.

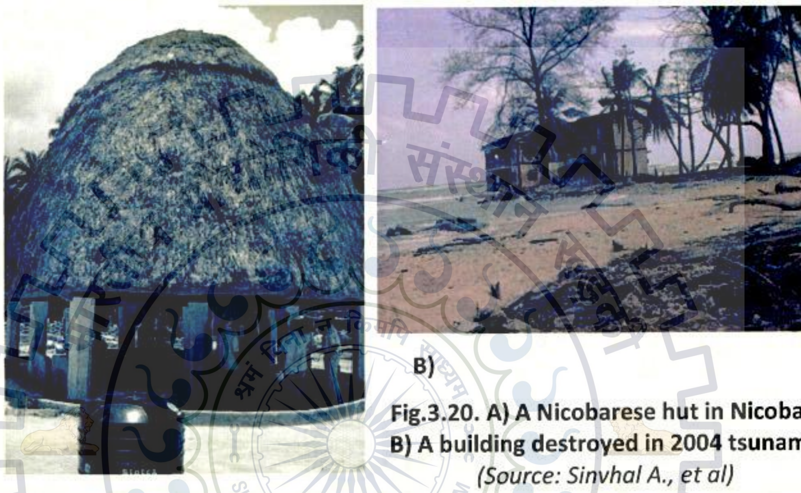
### *3.3.4 Evolution and Vulnerability Index*

**Site:** Rock Outcrop
Slope/hilly terrain
**Design:** Regular Plan
<u>Internal walls</u>
Walls above one another
Change in layout
<u>Ceiling height</u>
Less
More
<u>Size of openings</u>
Small
Large
<u>Distance between logs</u>
Closely packed
Increased
Additional external verandah
Provision of vertical shear key



## 3.4 Nicobarese huts, Car Nicobar

Magnitude 9.0 Sumatra earthquake of 26th December, 2004 greatly affected the Nicobar group of Islands. It was the fifth largest earthquake occurred since 1900. Approximately 15,000 casualties were reported in India alone. The earthquake at the interface of Indian and Burma plate was followed by a destructive tsunami and caused wider damage than earthquake. Islands are mainly inhibited by tribal population and their traditional practice of house making, survived while the modern life perished. The traditional nicobarese huts are simple huts for tribal joint family made of natural materials and easy to reconstruct if damaged.



A) B)

**Fig.3.20. A) A Nicobarese hut in Nicobar**
**B) A building destroyed in 2004 tsunami**
*(Source: Sinvhal A., et al)*

### *3.4.1 General features of the structures*

- The huts are circular in plan and made entirely of timber and natural materials.
- Usually there is a single room with one tall post at the centre to support the dome shaped roof.
- The hut is made on stilts i.e. supported on vertical timber posts (height 6' to 8')
- Floor of the hut rests on the horizontal timber members and consists of stiff wooden mat with perforation (for good ventilation in humid climate) on split bamboo floor.
- Wall is a timber (split cane) skeleton also covered with mat.
- The roof dome is made of local thin stems of wood covered over by thick dry bushes.
- Coconut tree stem are used for horizontal and inclined supporting member.
- All connections are tied by rope. No nails are used.
- Ladder is used for access to the hut.
- Comfortable (ventilated properly), eco friendly and earthquake resistant.


**Fig.3.21. A) A Nicobarese hut on timber stilts and ladder for access** *(Source: Rawal.V, et.al)*
**B) Interior of the hut showing perforated mat** *(Source: Sinvhal A., et al)*

### *3.4.2 Design evolution*

- Change in plan from circular to rectangular or square.
- Timber stilts replaced by plain concrete stilts.
- Use of concrete moreover with poor quality concrete mix consisting of sea gravel, sand and cement in the ratio 4:6-10:1.
- Water mixed without any measurement, to make the concrete workable. No steel used.
- Construction of masonry walls instead of wooden mat. (or walls made of same mix as that of concrete column)
- Sometimes, there is no connection between the concrete stilts and the horizontal wooden floor members.
- Dome shaped roof modified to hipped roof with sloping GI sheets.
- Stilts got shorter and gradually disappeared.


**Fig.3.22. Evolution in design of Nicobarese huts**

### *3.4.3 Earthquake resistant features*

- Indigenous people had knowledge about earthquakes and tsunami.
- Long stilts, the basic purpose of which was to avoid the contact with water, were not displaced during the earthquake in many huts.

- Good site selection like the huts were constructed on high and firm ground which saved them from high waves and ground shaking also.
- Light construction materials used in huts does not induce earthquake forces.
- These huts have high flexibility, thus whole structure moves with the earth during earthquake.

### 3.4.4 *Evolution and Vulnerability Index*

| | VULNERABILITY | | |
|---|---|---|---|
| | MORE | LESS | LEAST |
| **Site:** Coastline | ● | | |
| Higher grounds | | | ● |
| **Design:** <u>Plan</u> | | | |
| Circular | | | ● |
| Rectangular | | ● | |
| <u>Stilts</u> | | | |
| Wooden | | | ● |
| Concrete (Poor mix & improper connection) | ● - - - | - - - \| | |
| No stilts | ● | | |
| <u>Connections b/w stilts & superstructure</u> | | | |
| Present | | | ● |
| Absent | ● | | |
| **Material:** <u>Walls</u> | | | |
| Wooden | | | ● |
| Masonry | ● | | |

## 3.5 Dhajji-Dewari houses, Kashmir

This traditional style found mainly in western Himalayas, is a style developed by people to survive in adverse seismic conditions. These structures performed reasonably well than other types of construction during 8th Oct 2005 earthquake (M 7.6) in which 86,000 people were killed. An example of survival of 3 storied dhajji dewari house was seen, within the epicentral distance of 30 km, in the Baramulla district post-earthquake. Though the house was damaged but all its occupants were saved.

**Fig.3.23. Dhajji dewari structure in Kashmir**
*(Source: Randolph Langenbach)*

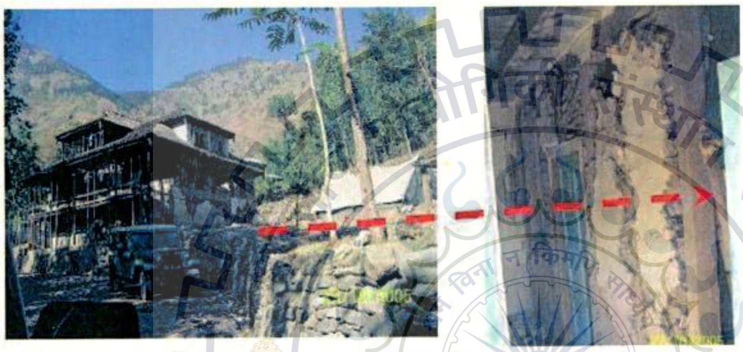


**Fig.3.24. 3 storied dhajji house that survived the earthquake in Sarai Bandi village, Baramullah** *(Source: A.Sinvhal, et.al)*

### *3.5.1 General features of the structures*

- Construction is generally square or rectangle in plan.
- Houses are typically 1-4 storeys tall.
- Superstructure consists of elaborate braced timber framework.
- Spaces between bracing and frame filled with stone or
  brick masonry which is laid in mud mortar.
- Timber framing and bracing is erected first, so that the masonry does not directly carry vertical load.
- Finished walls are plastered in mud mortar.
- Roof is either flat timber and mud roof or pitched roof of GI sheets.
- Roof is generally laid first to stabilise the timber

**Fig.3.25. Dhajji dewari house showing bracing, masonry and mud plaster**
*(Source: World Housing Report #146)*

**Fig.3.26. Shallow foundation of rubble stones** *(Source: World Housing Report #146)*

framework and keep the work dry.

- Floors of the house are made with timber beams that span between opposite walls.
- Timber floor boards are overlain by layer of mud.
- Structure is made on shallow foundation of rubble stone masonry.

**Fig.3.27. Timber framework and bracing with pitched roof** *(Source: WHR#146)*

### 3.5.2 Design evolution

- Addition of new space, to the old existing construction, by building upward or horizontally.
- Anchoring of timber plinth beam to the foundation instead of directly keeping it on plinth.
- Raising plinth beam above the ground to avoid rotting of timber instead of building frame directly on the ground.

**Fig.3.28. Evolution in connection of plinth to the foundation** *(Source: World Housing Report #146)*

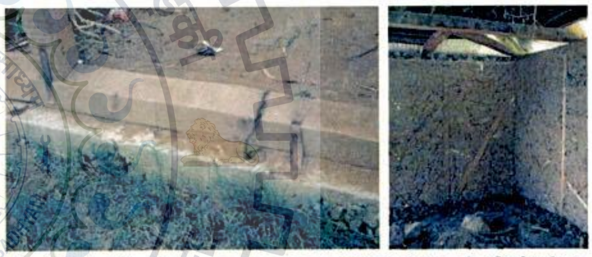


**Fig.3.29. Plinth beam above ground instead of placing directly on ground** *(Source: World Housing Report#146)*

- Providing nailed and strap connections instead of just wooden joints.
- Evolution of various types of extensive bracing patterns.
- Sometimes, timber and stones are laid in concrete. Holds risk of entire panel fall out as rigid object.

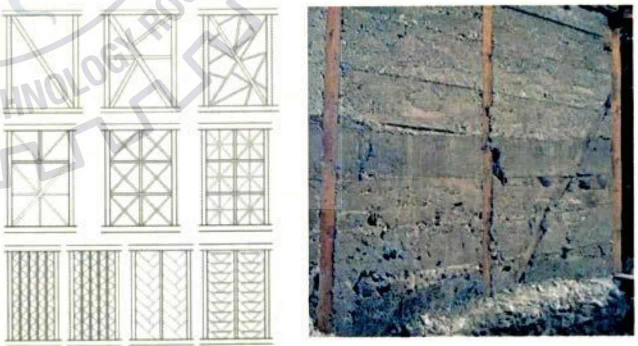


**Fig.3.30. Various bracing patterns and masonry laid in concrete** *(Source: World Housing Report #146)*

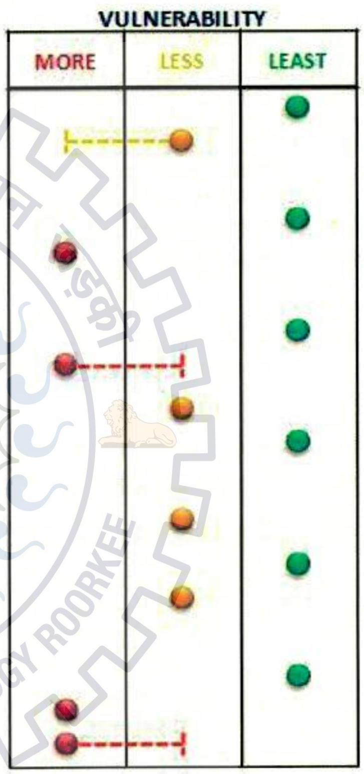
### 3.5.3 Earthquake resistant features

- Weak mud mortar allows infill masonry panels to quickly crack in-plane. Thus energy is absorbed through friction against timber frame.
- Timber bracing embedded within the masonry wall minimizes the propagation of diagonal shear cracks.

- The interconnected timber frame imparts ductility and flexibility, thus large displacements are sustained during strong ground shaking.
- The extensive framework helps in keeping the masonry wall relatively thin. Thus mass of the building and the inertial forces that must be resisted during earthquake are reduced.
- Doors and windows are few, small, well distributed and are kept away from the cross walls and edges of the wall.
- Wooden staircase occupies negligible space as compared to the size of the house.

### *3.5.4 Evolution and Vulnerability Index*

**Site:** Flat
Slope/hilly terrain
**Design:** Foundation
Raised above ground as plinth
No foundation
Connections
Present b/w plinth & plinth beam
Absent b/w plinth & plinth beam
Wooden joints
Wooden joints secured by nails/straps
Wall bracing
Simple
Extensive
Addition of new space without connection
**Material:** Mortar & Plaster
Mud
Concrete
Use of round stones in infill



## 3.6 Conclusion of this chapter

With the help of vulnerability index, the least vulnerable or the desirable features of the studied vernacular structures can be known so as to make these structures more resilient. The building parameters that need to be avoided are marked in red on the vulnerability index and those with moderate effect are less vulnerable. The modifications done over time in the construction of these structures have relation with their vulnerability. The modifications are sometimes good for increasing the resilience of the structure or vice-versa. For example in Dhajji dewari houses, earlier there was no connection between the plinth and the plinth beam that made the structure vulnerable but later modification by providing connection makes this feature desirable as the vulnerability is decreased. Similarly in Nicobarese huts, the tradition was to build structures on a higher ground which is a desirable feature. But with due course of time, people moved towards the coast and started building on the coastline, this modification is not desirable as it increases the vulnerability of the structures.

Also it is concluded that despite of the worst scenarios like the rugged mountain terrain, dry harsh areas and the rough island arc, these structures have survived and shown efficacy in such scenarios. Indigenous technical knowledge and locally available materials used in the construction of these earthquake-resistant structures in suburban and rural areas empower the communities to build a resilient built environment.

# 4. Risk Assessment

Risk assessment is a useful technique in estimation of losses due to an earthquake in a community over time. When these losses are identified, then it becomes suitable for the community to evaluate the benefits of various measures such as, preparedness and emergency responses, to reduce losses.

## 4.1 Study Area

This part of the dissertation deals with the risk assessment of the area under one of the seismic source zone (SSZ). SSZ is an area demarcated based on the density of seismicity cluster and tectonic elements around them. In a research paper, *'Probabilistic seismic hazard assessment in the vicinity of MBT and MCT in western Himalaya' by Mridula et al (2014),* nine seismogenic source zones has been identified. These are: Kangra SSZ, Uttarakhand SSZ, Western Syntaxes SSZ, Kaurik SSZ, Kashmir SSZ, Western Tibet SSZ, Karakoram SSZ, Jhelum SSZ, Indo Gangetic SSZ. (As already discussed under the heading 2.4 Literature review)

### *4.1.1 Selection of seismic source zone*

The Kangra seismogenic source zone has been selected for the risk assessment of the districts falling in this zone.

**Why Kangra SSZ?**

The great 1905 Kangra earthquake of magnitude 8.0 has already occurred in this seismogenic source zone. No other source zone has observed earthquake of this magnitude. Also the magnitude 7 earthquake is overdue in this source zone which according to Mridula et al (2014) was expected in temporal range of years 1938 and 1966. But no earthquake of magnitude 7 or above occurred in Kangra SSZ after 1906. The research also states that highest PGA (Peak Ground Acceleration) contour of range between 0.013 g to 0.315g is observed in this zone with Kangra and Chamba districts of Himachal Pradesh having highest PGA value. This makes Kangra SSZ more vulnerable as compared to other source zones. Considering the extent of urbanization and techno economic development, if a similar event as of 1905 occurs again, it would be catastrophic in view of increased population and built environment. Thus it is important to analyze the risk in terms of life loss and building damage in this source zone.

The Kangra source zone covers an area of 24,013 sq km. It is demarcated by MBT, MCT, Kishtwar fault and Sundarnagar fault. This source zone is selected for the risk assessment of various districts lying in this zone. Following districts (mentioned with the % of area) of Himachal Pradesh and contiguous Jammu & Kashmir lie in this source zone: Bilaspur (79.2%), Chamba (94%), Hamirpur (100%), Kangra (71.2%), Kullu (4.2%), Lahul & Spiti (13.2%), Mandi (42%), Solan (6.3%), Una (10.3%) of Himachal Pradesh and Udhampur, Kathua, Doda of J&K[1]. Following figure shows the districts lying under Kangra SSZ with MBT passing through Chamba, Kangra, Mandi and Bilaspur.

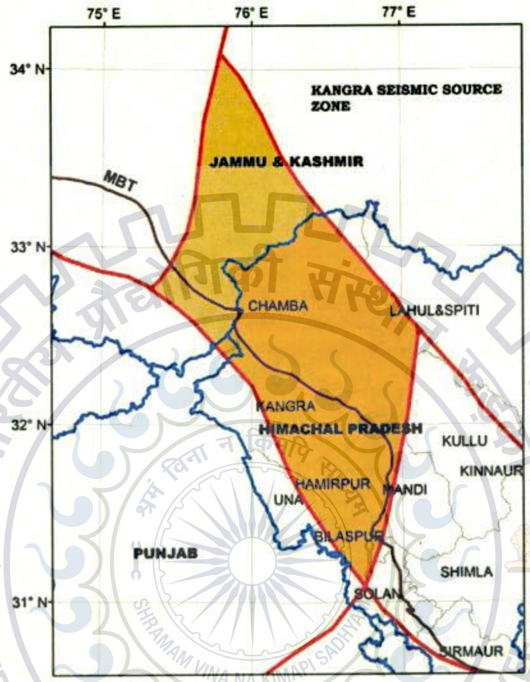



**Fig.4.1. Image showing area under Kangra SSZ with states, districts and MBT**

## 4.2 Methodology for Risk Assessment

The methodology for risk assessment of the districts under Kangra SSZ is adopted from the publication of *Bihar State Disaster Management Authority, 'Damage Scenario under hypothetical recurrence of 1934 earthquake intensities in various districts in Bihar, 2013',BSDMA.*

Assessment of risk is based on several factors such as type of construction and type of roof of houses, expected grade of damage, average population per house, and time of occurrence of an earthquake. These factors vary from place to place and time to time. Some of these factors are discussed below.

[1] The risk assessment for the districts of Jammu & Kashmir is not done because of the unavailability of certain data.

### *4.2.1 Data inventory required for risk estimation:*

- Total population of each district taken from Census 2011 data.

- Data taken from *'Vulnerability Atlas of India, 2006'* includes total number of housing; number of houses with A, B, C type of walling material; number of houses with R1, R2, R3 category of roofing material; number of rural and urban houses; of each district.

*{Building types for specifying damage are classified as A, B and C types which are defined as follows (IS 1893 (Part 1) : 2002, Annex D) :-*

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

*The Vulnerability Atlas of India, 2006, defines three types of roofs, which were considered for estimation of life loss in this study. These are as follows:*

*R1: Light weight pitched roof,*
*R2: Pitched roof with heavy weight covering, and*
*R3: Heavy flat roof consisting of wood joists carrying bricks and earth fill, stone slabs, RB or RC roof slabs.}*

- Seismic zone of each district lying in the Kangra SSZ taken from *Seismic zoning map of India.* Himachal Pradesh falls in zone V and IV, thus few districts have some part in zone V and some in zone IV. So, the district having substantial area in a particular seismic zone is considered for calculation in that seismic zone.

- Percentage of houses under various damage grade G5 (collapse), G4 (destruction), G3 and G2 calculated from the formula as mentioned in *'Damage Scenario under hypothetical recurrence of 1934 earthquake intensities in various districts in Bihar, 2013' (Table 1, page 9)*

*{Classification of damage to buildings as damage grades, defined in (IS 1893 (Part 1): 2002, Annex D) are as follows:*

*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 walls 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; Pantiles slip off; Cracks in chimneys; Parts of chimney fall down*

*G1: Grade 1 - Slight damage*

*Fine cracks in plaster; fall of small pieces of plaster}*

### *4.2.2 Calculation of life loss*

For calculating life loss in each district three important factors are required, namely:

**R factor** that is average population per house in each district

***R= Total population/Total housing***

| Districts in Kangra SSZ | Total Population | Total Housing | R factor |
|---|---|---|---|
| MANDI | 999777 | 382844 | 2.61 |
| HAMIRPUR | 454768 | 176610 | 2.57 |
| KANGRA | 1510075 | 503503 | 2.99 |
| BILASPUR | 381956 | 135407 | 2.82 |
| KULLU | 437903 | 152865 | 2.86 |
| CHAMBA | 519080 | 173537 | 2.99 |
| UNA | 521173 | 155774 | 3.35 |
| LAHUL & SPITI | 31564 | 17222 | 1.83 |
| SOLAN | 580320 | 182288 | 3.18 |

**L factor** that is Light roof reduction factor

The collapse of R3 type of roof i.e heavy flat roof is liable to cause maximum casualties but the R1 type of roof i.e sloping light weight roof can cause severe injurious and is not life threatening. Collapse of R2 type of roof will have in between effect i.e injuries and casualties. Thus the roof types have major effect on the life of the inhabitants. L factor is thus a consideration for type of roof.

***L= {10 % of R1 + 30% of (R2 + R3)} / Total Housing***

| Districts in Kangra SSZ | Total Housing | R1 | R2 | R3 | L factor |
|---|---|---|---|---|---|
| MANDI | 382844 | 43202 | 252956 | 86686 | 0.28 |
| HAMIRPUR | 176610 | 10365 | 120090 | 46155 | 0.29 |
| KANGRA | 503503 | 39369 | 325567 | 138567 | 0.28 |
| BILASPUR | 135407 | 22910 | 63856 | 48641 | 0.27 |
| KULLU | 152865 | 37932 | 92853 | 22080 | 0.25 |
| CHAMBA | 173537 | 78710 | 76389 | 18438 | 0.21 |
| UNA | 155774 | 36315 | 36035 | 83424 | 0.25 |
| LAHUL & SPITI | 17222 | 15327 | 24 | 1871 | 0.12 |
| SOLAN | 182288 | 81669 | 8946 | 91673 | 0.21 |

**F factor** that is Favourable condition factor

An earthquake may occur at any time of the day. For example, the Kangra earthquake of 1905, Mw =8.0, (MHD) occurred on 4th April in the morning at 06:20 AM (IST). At that time most of the people were sleeping in their homes, hence there was a very large casualty. This was among the deadliest earthquakes in modern Indian history. Nearly 19,800 people were killed and thousands were injured in and around Kangra district, mostly due to collapse of buildings. Damages extended into the Dehradun area of Uttarakhand. Extensive landslides and rockfalls occurred in the region. Thus, loss of life is dependent on time of occurrence of an earthquake, and two categories have been identified, favourable and unfavourable time of day.

The life loss is calculated for different time of occurrence of earthquake. The earthquake can occur at a favourable time, that is, when the occupancy in the houses is low for example during day time when people are out for work. It can also occur at unfavourable time when the occupancy in the houses is high for example during night time when people are sleeping in their houses. Thus it is clear that life loss will be higher if earthquake occurs during unfavourable time. For favourable time of occurrence F is calculated by below equation while for unfavourable time it is unity.

***F= {0.3 * Rural housing + O.5 * Urban Housing} / Total Housing***

| Districts in Kangra SSZ | Urban Housing | Rural Housing | Total Housing | F factor |
|---|---|---|---|---|
| MANDI | 25150 | 357694 | 382844 | 0.31 |
| HAMIRPUR | 12178 | 164432 | 176610 | 0.31 |
| KANGRA | 27439 | 476064 | 503503 | 0.31 |
| BILASPUR | 10188 | 125219 | 135407 | 0.32 |
| KULLU | 13982 | 138883 | 152865 | 0.32 |
| CHAMBA | 11864 | 161673 | 173537 | 0.31 |
| UNA | 15533 | 140241 | 155774 | 0.32 |
| LAHUL & SPITI | 0 | 17222 | 17222 | 0.3 |
| SOLAN | 35313 | 146975 | 182288 | 0.34 |

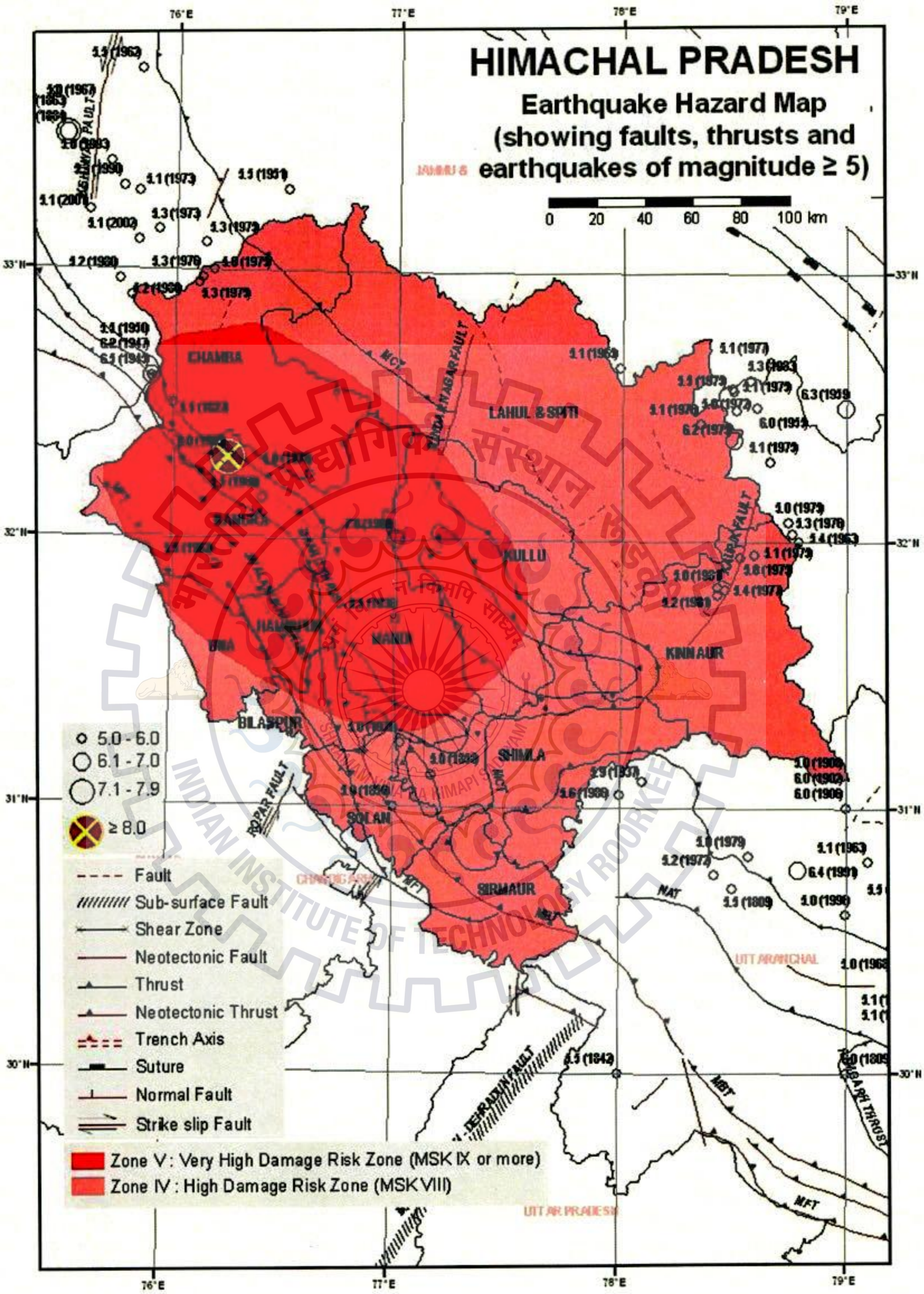
After calculating these factors, number of houses under damage grades 5 & 4 (i.e NG5 & NG4) are calculated using following table:

| Type of building | Zone III<br>Intensity : MSK VII | Zone IV<br>Intensity : MSK VIII | Zone V<br>Intensity : MSK IX or More |
|---|---|---|---|
| A | 10% : G4<br>75% : G3<br>Rest : G2 or, (G1 | 10% : G5<br>75% : G4<br>Rest : G3 or, G2 | 50% : G5<br>Rest : G4 or, G3 |
| B | 10% : G3<br>50% : G2<br>Rest : G1 | 10% : G4<br>75% : G3<br>Rest : G2 | 10% : G5<br>50% : G4<br>Rest : G3 |
| C | 10% : G2<br>50% : G1<br>Rest : No damage | 10% : G3<br>75% : G2<br>Rest : G1 | 10% : G4<br>50% : G3<br>Rest : G2 |
| D | 10% : G1<br>Rest : No damage | 10% : G2<br>Rest : G1 or, No damage | 10% : G3<br>50% : G2<br>Rest : G1 |

**Table 4.1: Number of Housing having various Damage Grades in different Seismic Zones**
(*Source: 'Damage Scenario under hypothetical recurrence of 1934 earthquake intensities in various districts in Bihar, 2013' (Table 1, pg 9)*)

Losses of human lives were considered in grades G5 and G4 i.e. damage grades of collapse and destruction of building, while life loss in grades G3 and G2 were assumed to be nil. Those buildings which suffered damage of grade G4 and G5 contributed maximum in the increased number of life loss, since most casualties occurred in collapsed houses.

Damage to the houses of each category is calculated on the basis of seismic zoning map of India. All the districts in Kangra SSZ lie in seismic zone V and IV. Various districts have some part in zone V and some part in zone IV. So for the purpose of calculation, district having major part in any of the zone is considered for that zone. For example, Chamba has more than 50% of its area under zone V, so the damage grade calculation is considered for zone V.




BMTPC : Vulnerability Atlas - 2nd Edition; Peer Group, MoH&UPA; Map is Based on digitised data of SOI, GOI; Seismic Zones of India Map IS:1893: 2002; Seismotectonic Atlas of India, GSI, GOI

**Fig.4.2. Map showing Seismic Zoning of Himachal Pradesh**

For Zone V, number of houses under damage grade G5 is given by following equation

$$\mathbf{NG5_V = 0.50\ nA_V + 0.10\ nB_V}$$

And damage grade G4 is given by $\mathbf{NG4_V = 0.25\ nA_V + 0.50\ nB_V + 0.10\ nC_V}$

Similarly, For Zone IV number of houses under damage grade G5 is given by

$$\mathbf{NG5_{IV} = 0.10\ nA_{IV}}$$

And damage grade G4 is given by $\mathbf{NG4_{IV} = 0.75\ nA_{IV} + 0.10\ nB_{IV}}$

Where,

nAV, nBV and nCV = number of houses of type A, B and C, respectively in zone V.

nAIV and nBIV = number of houses of type A and B, respectively in zone IV.

After calculation of number of houses under damage grade 5 and 4 in each district, loss of human lives is estimated for both unfavourable and favourable time of occurrences of earthquake.

For district in zone V, estimated life loss

- For unfavourable time of occurrence

$$\mathbf{Life\ loss = L\ \ R\ (0.06\ NG5_V + 0.02\ NG4_V)}$$

- For favourable time of occurrence

$$\mathbf{Life\ loss = F\ \ L\ \ R\ (0.06\ NG5_V + 0.02\ NG4_V)}$$

For district in zone IV, estimated life loss

- For unfavourable time of occurrence

$$\mathbf{Life\ loss = L\ \ R\ (0.06\ NG5_{IV} + 0.02\ NG4_{IV})}$$

- For favourable time of occurrence

$$\mathbf{Life\ loss = F\ \ L\ \ R\ (0.06\ NG5_{IV} + 0.02\ NG4_{IV})}$$

The results of life loss risk estimation are tabulated below in Table 2:

**Table 4.2: Total number of houses of each Type and number of houses under G5 and G4 grade of damage in districts of Kangra source zone. Calculation of life loss under unfavourable and favourable time of occurrence**

| District in Kangra SSZ | Seismic Zone | No. of Type A houses | No. of Type B houses | No. of Type C houses | Number of houses under damage grade of G5 (NG5) | Number of houses under damage grade of G4 (NG4) | Life Loss for unfavourable time of occurrence for % of area in SSZ | Life Loss for favourable time of occurrence for % of area in SSZ | % of unfavourable life loss with respect to district population | % of favourable life loss with respect to district population |
|---|---|---|---|---|---|---|---|---|---|---|
| Mandi | V | 3,32,412 | 35,945 | 11,652 | 1,69,801 | 1,85,344 | 4,228 | 1,324 | 1.01 | 0.32 |
| Hamirpur | V | 1,16,231 | 57,598 | 1,157 | 63,875 | 87,030 | 4,137 | 1,298 | 0.91 | 0.29 |
| Kangra | V | 3,27,558 | 1,63,985 | 3,541 | 1,80,178 | 2,46,126 | 9,524 | 2,961 | 0.89 | 0.28 |
| Bilaspur | V | 96,252 | 35,759 | 1,560 | 51,702 | 66,162 | 2,631 | 829 | 0.87 | 0.27 |
| Kullu | V | 1,21,394 | 15,488 | 13,910 | 62,246 | 69,832 | 155 | 49 | 0.84 | 0.26 |
| Chamba | V | 1,53,335 | 15,175 | 2,934 | 78,185 | 84,549 | 3,756 | 1,178 | 0.77 | 0.24 |
| Una | V | 53,456 | 96,229 | 1,323 | 36,350 | 74,974 | 321 | 103 | 0.60 | 0.20 |
| Lahul Spiti | IV | 16,269 | 184 | 141 | 1627 | 12,220 | 10 | 3 | 0.24 | 0.07 |
| Solan | IV | 88,269 | 87,235 | 1,829 | 8,827 | 74,925 | 86 | 29 | 0.23 | 0.08 |

### *4.2.3 Calculation of Building Reconstruction and Repairing*

For estimation of number of buildings that might get damaged and require reconstruction and repairing, buildings under damage grade G5, G4, G3 and G2 need to be calculated. Total number of houses under damage grade G5 and G4 shall be reconstructed and that under G3 and G2 shall be repaired.

**Estimated Reconstruction = NG5 + NG4**

**Estimated Repairing = NG3 + NG2**

Probable number of houses in each district that will require reconstruction and repairing is tabulated below in Table 3:

**Table 4.3: Number of houses under G5, G4, G3 and G2 grade of damage in districts of Kangra source zone. Calculation of building damage in terms of Reconstruction & Repair**

| District in Kangra SSZ | Seismic Zone | Number of houses under damage grade of G5 (NG5) | Number of houses under damage grade of G4 (NG4) | Number of houses under damage grade of G3 (NG3) | Number of houses under damage grade of G2 (NG2) | Reconstruction for % of area in SSZ | Repair for % of area in SSZ |
|---|---|---|---|---|---|---|---|
| Mandi | V | 1,69,801 | 1,85,344 | 1,03,307 | 4,661 | 1,49,161 | 45,346 |
| Hamirpur | V | 63,875 | 87,030 | 52,675 | 463 | 1,50,905 | 53,138 |
| Kangra | V | 1,80,178 | 2,46,126 | 1,49,254 | 1,416 | 3,03,528 | 1,07,277 |
| Bilaspur | V | 51,702 | 66,162 | 39,147 | 624 | 93,348 | 58,838 |
| Kullu | V | 62,246 | 69,832 | 43,499 | 5,564 | 5,547 | 2,061 |
| Chamba | V | 78,185 | 84,549 | 45,871 | 1,174 | 1,52,969 | 44,222 |
| Una | V | 36,350 | 74,974 | 52,517 | 529 | 11,466 | 5,464 |
| Lahul Spiti | IV | 1,627 | 12,220 | 1,372 | 1,354 | 1,828 | 360 |
| Solan | IV | 8,827 | 74,925 | 72,229 | 21,077 | 5,276 | 5,878 |

## 4.3 Results of Risk Assessment

Assessment of risk is done in terms of number of life loss and building damage using housing data from Vulnerability Atlas of India 2006 and population data from Census of India 2011. Ground effects such as landslide, liquefaction, rockfall and damming of river were not incorporated in the risk assessment.

After life loss estimation the results indicate that **Kangra** district would suffer maximum human casualty of 2961 during the favourable time of occurrence, i.e when occupancy in houses is usually the lowest, and more than three times as much, a staggering 9524 if this earthquake occurred at unfavourable time, i.e. when occupancy is highest, which turns out to be 0.28% and 0.8% of the population, respectively. Similar computations were made for other districts, and the risk in decreasing order is for Mandi, Hamirpur, Chamba, and Bilaspur, districts. It can be seen in table 1 that number of loss of life under favourable and unfavourable condition is more in Kangra as compared to Mandi but the percentage loss is high in Mandi which is 0.32% during favourable time and approx 1% during unfavourable time of occurrence hence maximum causalities will occur in **Mandi** with respect to the population in district.

After building damage estimation it is seen that Kangra will have highest reconstruction and repairing work of 3,03,528 and 1,07,277 buildings respectively. After Kangra damage to buildings is higher in Chamba in case of reconstruction where 1,52,969 of the buildings will need to be constructed again and in Bilaspur district the high where 58,838 of the building will need repairing.

Therefore, immediate and urgent disaster mitigation measures are required in these districts.

## 4.4 Other factors contributing to Risk

Seismic risk is the combination of hazard, vulnerability and exposure.

Seismic hazard is the potentially damaging phenomena corresponding to earthquakes, such as ground shaking, liquefaction, landslides, fissures, etc.

Seismic vulnerability is the building's susceptibility towards the damaging effect of hazard. It depends upon the type of building, material used, construction methodology, design.

Seismic exposure is the number of assets exposed to the hazard i.e. the population and also the time of occurrence of the earthquake. Human life is considered as the most important asset to be safeguarded during earthquake.

The risk assessment done considers the type of buildings and material as vulnerability factor and human population as exposure factor, to the earthquake. Therefore, the risk calculated is for the number of people living in various types of houses. Apart from this, other factors that can add on to the risk can be:

1. Geographical location of the human settlements- for example locations near the river or on the hilly slope can cause dangerous consequences during the earthquake.
2. Planning at structure and settlement level

### *4.4.1 Physiography of Kangra & Mandi district*

**K**angra district has an undulating landform because of its mountainous terrain. The altitude above mean sea level ranges from 550m to 5500m. Many deep valleys are formed between the ranges of varying elevation. Depending upon the altitude, the district can be divided in three zones:

1. Low hills and valley areas up to an elevation of about 900 metres from msl. This accounts for about 49% of the total area in the district.

2. Mid hills extending from 900 metres to 1,500 metres from msl. This is nearly 16% of the district area.

3. High hills rising from about 1,500 metres to 5500 metres from msl. This accounts for the remaining 35% of the area.

Main river of the district is river Beas and its tributaries. Southern flowing tributaries are perennial as they are snow fed. Northern flowing tributaries have flash flood during monsoon season. *(Human Development Report, Kangra)*

**M**andi district also has mainly mountainous terrain. Range of altitude is from 3962m (highest) to 548m (lowest). Main rivers are river Beas and Sutlej. The mandi town sits on the bank of river Beas. *(Human Development Report, Mandi)*

### *4.4.2 Few susceptible areas*

According to the results of risk assessment, Kangra and Mandi district will suffer maximum life loss.

During 1905 Kangra earthquake, many landslides, rockfalls and avalanches were triggered on the hill slopes surrounding Kangra and Dharamshala town. In a village near Mandi, some massive rockfalls resulted in terrible deaths when many houses were crushed under the falling rock. The ground motion at Dharamshala was so strong that many fissures were seen at a location and a deep slump along an old fracture. Even the plain areas underwent damage. In the nearby plain locations like Haridwar and Roorkee, sand vents and earthquake fountains were reported.

During 1997 Sundernagar earthquake (M 5.0), most damage was reported from the localities situated on alluvial plains of Lindi river. Houses located on river bed were damaged in few seconds of shaking. *(Earthquake Hazard Profile of the State, HPSDMA)*

Inspite of such cases, seismicity of the region is underestimated in context with the location of the construction. Earthquakes in the Himalayan belt trigger massive landslides which may in turn cause situations like flash floods because of the blockage of river course. Thus the additional factors like- physiography and planning of the human settlements that contribute to risk in these districts, is identified through satellite images. Here images of few susceptible areas are shown, which can be at risk due to their location and geographic features around them. During earthquake, hazards that are initiated in hilly terrain (as in Kangra and Mandi) can be landslides, rockfalls, avalanche and flash floods which can greatly affect these areas.

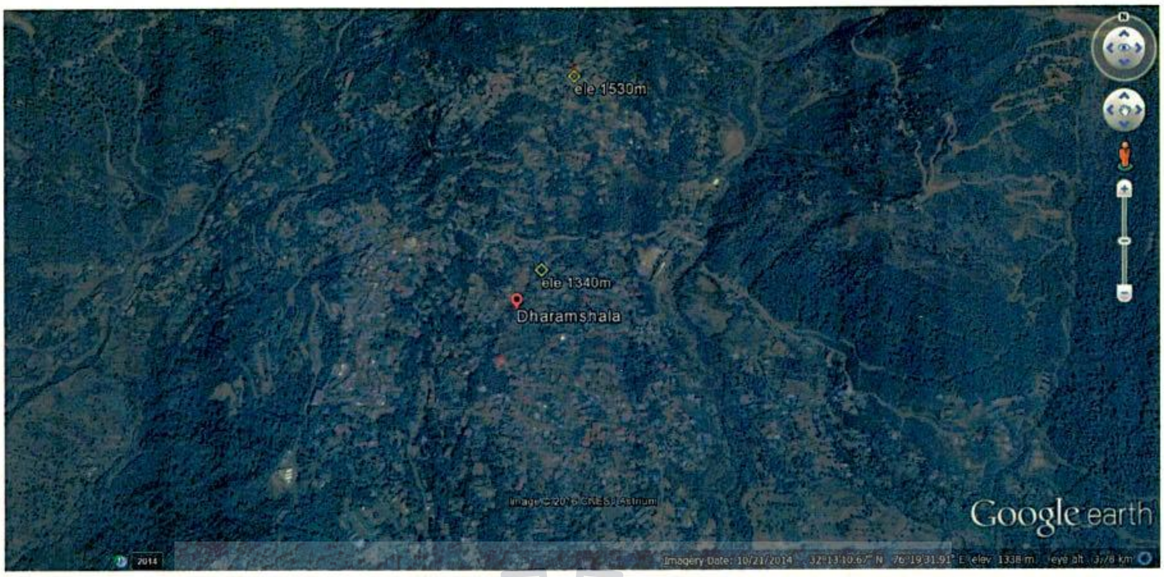



Fig.4.3 A) Dharamshala in Kangra district

**D**haramshala, lying on the spur of Dhauladhar range, is the district headquarters of the Kangra district. It is a growing city with lot of modern development coming up on its hilly terrain. Reason behind this development is that Dharamshala is a place of tourist interest. Mc leodganj in its upper reaches is home to Dalai lama. During the 1905 earthquake, Dharamshala and Mc leodganj were most affected areas. But still the lesson is not learnt. Modern construction, irrespective of proper planning and hazards, is happening with the availability of area for construction. Satellite image shows the settlements that have covered the hill from ridge to valley.

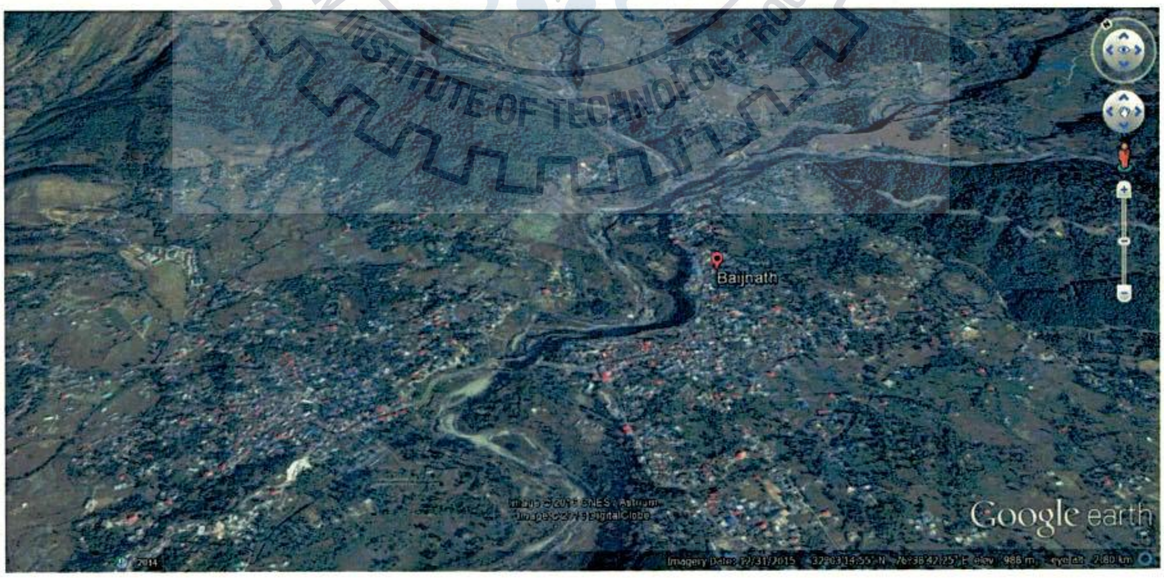



Fig.4.3 B) Baijnath in Kangra district

**B**aijnath is a town in kangra district famous for its Shiva temple. The town is located on the bank of river Binwa, a tributary of major river Beas. The temples in this town and the view of Dhauladhar range is the attraction for tourists and thus lot of construction can be seen along the river. Considering the physiography, the settlements can be seen around the intersection of two streams and then continuing along the river edge. This can be a dangerous situation if due to earthquake, streams get flooded and because of the elevation difference, the construction near the river can be washed off. Roads can be seen on the steep slopes which can propagate landslide during earthquake activity and damage constructions at the foothill.


**Fig.4.3 C) Palampur in Kangra district**

**P**alampur is a town located at the junction of plains and the hills. Numerous streams from the snow peaks of Dhauladhar range spread in the plains. Streams may remain dry during the winter season but get water during the summers. The settlements located in the plain area may suffer liquefaction damage, because of abundance of water, during earthquake. And those at the gradually rising elevation can be prone to mudslides.

**M**andi is the major city of the Mandi district. River Beas runs through the city and is surrounded by hills. Heavy settlements are on the banks of this river beyond which the hilly terrain is steep. If closely observed this can be a similar case as that of Kedarnath disaster. The constructions so close to the river and on the steep slopes of the surrounding hills can be at high risk during earthquake. Massive landslides can initiate flooding of the table land on which main city is located. Surrounded by hills, landslides and rockfall can destroy the construction in the valley. Sand bars are also formed on the banks of the river.

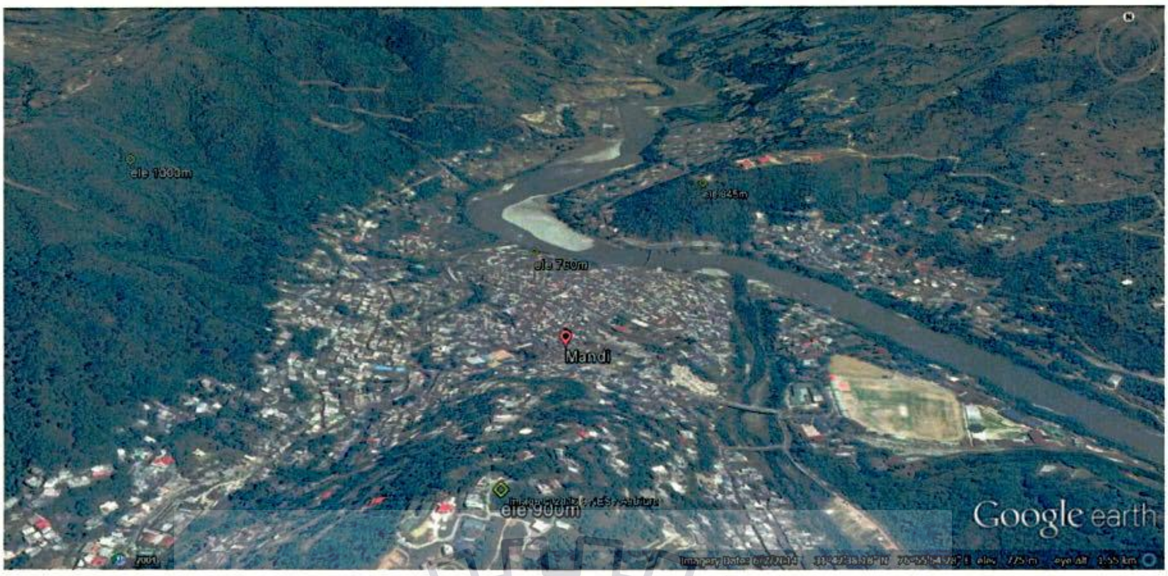



**Fig.4.3 D) Mandi in Mandi district**


**Fig.4.3 E) Jogindernagar in Mandi district**

Jogindernagar is a town located in the valley, surrounded by hills on all sides, in Mandi district. Various streams from the surrounding hills pass through the region on gentle slope. Flash floods can be initiated in this area if landslides happen on the upper reaches due to earthquake. Also there are few hydro-electricity power station that can affect the settlements, if get damaged due to high intensity earthquake.

# 5. Discussions

In this chapter, learning's from the earthquake resistant vernacular structures is mentioned keeping in view the physiography i.e. the hilly terrain, where mainly vernacular techniques have developed for years. As the high risk areas assessed earlier have similar type of terrain. Lessons learnt from the vernacular approach forms the basis for the suggested measures. In chapter 3, resilience of vernacular structures is discussed at building level and in next chapter, the risk is assessed at district level. Thus the measures can be applied at building level but at the settlement level it is not easy to change the planning according to the risk. Still the measures can be useful for the new developments which may come up in these risk zones.

## 5.1 Lessons learnt from vernacular approach

- The vernacular structures have survived for years in difficult terrains by following simple construction techniques. The development of traditional settlements are carried out with careful consideration of the context i.e. the surrounding physiographic features. The structures are generally constructed along the contours so as to reduce the site development work which involves cutting and filling of slopes. Usually the firm ground is used for construction. Vernacular structures merge well with the surrounding environment and have minimum impact on environment.

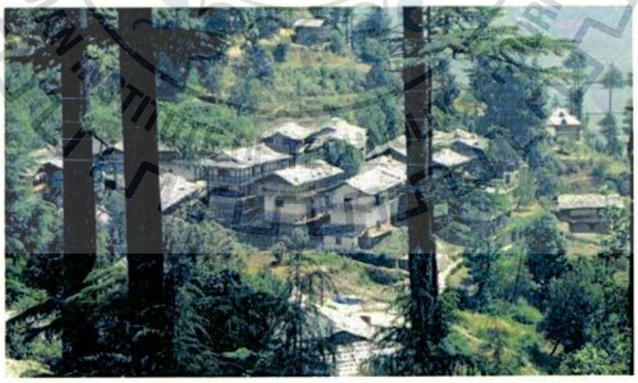


**Fig.5.1. Image showing vernacular settlement in the Himalayan region**
*(Source: Kumar, A.et al. 2013)*

- In vernacular construction, the structures are planned such that they are separated from each other. And also they are clustered around an open space. During the dormant period, such planning is helpful in making the houses climate responsive (E.g. More exposure to the sun in cold hilly climate and avoiding mutual shading). The open spaces become the gathering area for the community, for different purposes.

But during the earthquake, every structure has a proper earthquake gap as no other structure comes in its immediate vicinity.

Thus the shaking of one structure during earthquake does not affect the other and structures are safe. The open spaces at such time become the escape zones where people can collect safely.

**Fig.5.2. Sketch showing Koti banal houses in Kangra valley** *(Source: Middlemiss 1910)*

- Planning of vernacular structures is always compact. The ground covered by built up area has small footprint on the open area. This area is used for vegetation purpose that helps in holding the soil and making slope stable in case of landslide. Other natural materials are also used for slope stabilisation which in modern day is done by constructing retaining wall. Materials like branches of trees, bamboo, field stone, etc. are used.

- Vernacular structures follow the best form of geometry that makes them resilient. Plan of the houses are circular (as in bhunga houses), square or rectangular in correct proportion (as in dhajji, ikra and koti banal houses). Symmetry is not only maintained in the perimeter of the plan and elevation but also in the internal planning of walls and openings. In modern construction deviation from the regularity (like provision of soft storey) can be seen which increases the vulnerability.

- Ductility is an important factor in all vernacular structures that use wood/bamboo in wall construction. This helps in dissipation of energy during lateral loading and damage in a controlled way.

- Vernacular construction practices like dhajji dewari, kat ki kunni and wooden buildings use locally available materials which are timber, stone and thatch mainly. Heterogeneous use of materials mainly in walls is given much focus on because wall thickness and horizontal wall members play a key role in resisting lateral loads.

## 5.2 Suggested Measures to increase resilience

### *5.2.1 Settlement Level*

- The state of Himachal Pradesh has a hilly terrain. Also the MBT passes through districts of Chamba, Kangra, Mandi, Bilaspur, Solan in the Kangra source zone, thus increasing the hazard level. The nature of landforms in such areas becomes unpredictable in case of earthquakes. Modern construction is rushing on the hills, weakening the slope stability due to heavy concentrated construction. Development on hilly terrains should be in a controlled manner and site development work i.e. mainly cut and fill method should be as minimum as possible. Following the vernacular approach, construction should be along the contour so as to have minimum impact on the slope and environment as well.

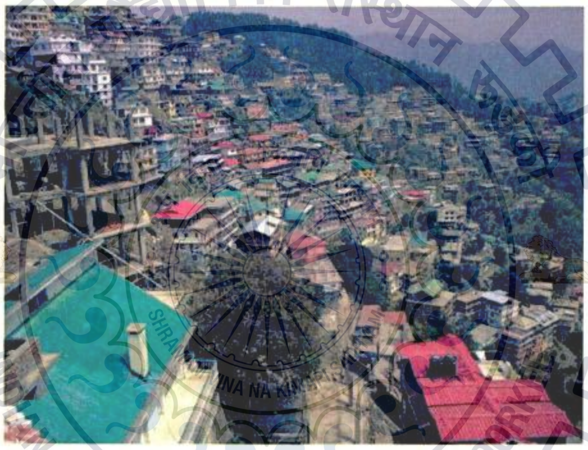


**Fig.5.3. Image showing multi storey modern construction on the hills**
*(Source: Kumar, A.et al. 2013)*

- For the new construction in the hilly terrain, the buildings should be planned in a way such that they are separated from each other and every building should have open space around them. During earthquake, this separation will act as earthquake gap as no building will lie in the immediate vicinity of the other building. Since the number of storeys will differ in every building, their behaviour (natural period) will be different during ground shaking. To avoid pounding between buildings this gap is required. Also the open spaces at such times become the escape zones where people can collect safely.

- The modern unplanned construction is also intruding the few existing traditional settlements. The figure below shows the old Koti Banal structure, in the Koti banal village, encroached by new construction. This practice needs to be stopped. Also these old structures are partly demolished so as to use their material in new buildings. This practice affects the dynamic behaviour of these traditional structures during earthquake shaking. Also the adverse effects are enhanced due to the lack of maintenance of these age old structures as they deteriorate structurally. Preservation of these structures is required so as they stand as examples for more years to come.

**Fig.5.4. Unplanned construction around a traditional house in Koti Banal village**
*(Source: World Housing Report #150)*

- Settlements should develop in areas where there are no notable landslides in the surroundings and should not be more than the carrying capacity of the slopes. New developments should be discouraged in areas of poor accessibility and high seismic hazard.

- Making communities resilient in rural remote areas by proper training in construction of homes similar to vernacular houses which have been earthquake resistant in past.

### 5.2.2 Building Level

- Not all traditional practices in high seismic zones are earthquake resistant like adobe or random rubble masonry houses. Their weakness is realised once an earthquake occurs and results are fatal which leads to evolution in building technique. But there exist outstanding earthquake resistant vernacular techniques which should be brought into practice in areas which though have not encounter earthquakes for over a commendable time but are located in severe seismic zones.

- It is important to do the site survey of the soil strata before construction of new building. According to the vulnerability index it can be seen that the most suitable and least vulnerable site is the flat terrain or a gentle slope or the site with rock outcrop (i.e. hard strata). This avoids the risk of landslides during earthquake. Also raising the structure above ground on strong plinth is beneficial.

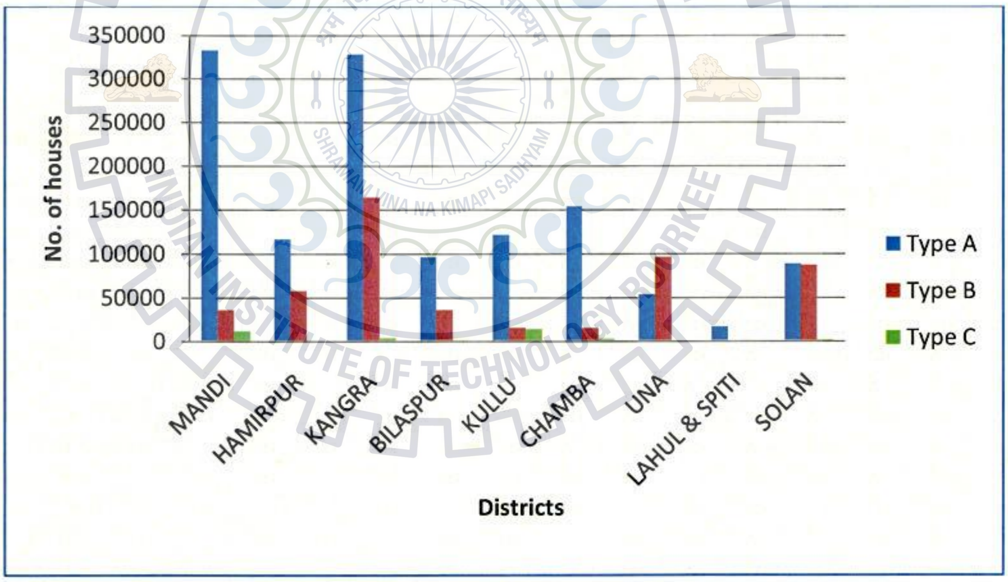
- Building standards of earthquake resistant vernacular structures are not same as that of modern structures. The difference in standards like geometry, storey height, size and position of openings, wall thickness, mixed walling material, etc. is for a reason, so as to make structure resilient to earthquakes. These standards should be adopted in modern construction built in severe seismic zones with conditions similar to that of vernacular structures.

  - Plan of the building should be regular in nature, preferably, rectangular as seen in vernacular construction (1:2 or in similar ratio).
  - The storey height in modern building is usually taken as 3.0m but in vernacular building it is less than this (2.4m to 2.7m). This helps in reducing the building height of multi-storey building, thus lowering the centre of gravity and making structure more stable during earthquake.
  - Size of the openings in vernacular structures is kept small so as to provide less hindrance in the path of lateral forces. Further these openings are empanelled with heavy frame so to make up for the loss of strength. Same standard should be followed in modern building wherever possible.
  - Placement of the openings also plays an important role. They should be uniform and symmetrical and placed away from the wall corner.
  - Thickness of the walls in vernacular construction is slightly more than that in modern construction. Thick walls made out of wood and stones not only protect from the cold hilly climate but also keep the building mass in close proximity with ground to provide stability and strength to bear the lateral loads.
  - Lightweight roof and materials helps in help in reducing the seismic force.

- Ductility of structure is useful in zones of ground shaking. Normal brick building is brittle in nature or less-ductile thus damage occurs at early stage and is more. Steel buildings are useful in such cases as they have high ductility thus undergo controlled damage. For energy dissipation and transfer the connections between ground, foundation and structural elements is important.

- Type 'A' buildings which are made out of locally available and low cost material like the buildings in field-stone, rural structures, un-burnt brick houses, clay houses; respond poorly during earthquake shaking. In case of intensity IX shaking they might suffer total destruction yet in the graph below, it is very clear that maximum houses fall under this category in each district. Type 'B' buildings which are burnt-brick houses are the next vulnerable category, if built without earthquake resisting features, is likely to suffer severe damage at high intensity. It was evident during 2005 Kashmir earthquake when thousands of people died due to collapse of stone masonry houses. Similarly, in 1905 Kangra earthquake the structures with sun dried brick walls were destroyed.

  These vulnerable house types can be modified by retrofitting and modifications as learnt from earthquake resistant vernacular structures like stable geometry, use of flat shaped stones, wooden enforcement at various levels, etc. can be done that can make




  this typology more resilient. By doing so, for example, the performance of type A building in vulnerability class A (made of field stone) can be improved up to class B (by inserting ties).

- For constructing a modern building in vernacular style it is not always easy to use locally available materials. The reason being, like felling of trees for timber will result in deforestation also it is expensive and have high maintenance cost. Similarly, timber and thatch both are vulnerable to fire. Thus innovation in materials can be done which can be utilized in same way as in vernacular practice. Example of such innovation is seen in a hotel in Pehalgam, Srinagar which is constructed in dhajji dewari style but with the use of modern materials, brick and steel, which are as durable and vernacular materials.

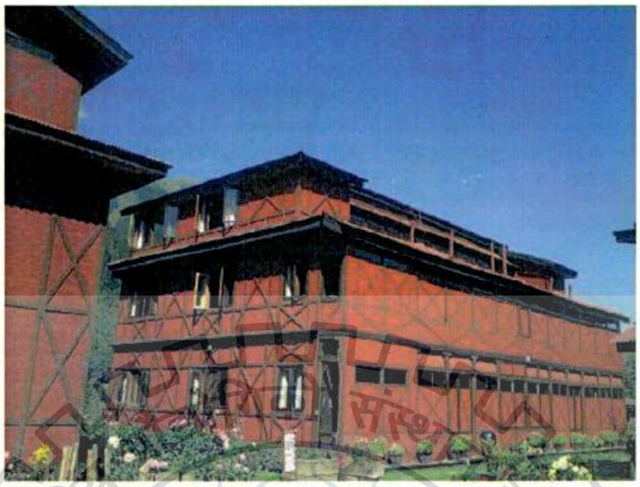


**Fig.5.5. Modern hotel building built in traditional style**
*(Source: Kumar, A. et al. 2013)*

- Earthquakes though have less probability of occurrence but consequences are more. For the new developments, it is better to include the earthquake resisting measures, in the structure, built-in during the construction stage itself. This will require very less extra expense. Providing seismic retrofitting after the construction is complete will be a complex and very expensive process. Earthquake resilient vernacular structures are constructed with the same technique of including resilient feature in the building parameters at construction stage. This traditional wisdom is the reason behind age old vernacular structures still standing firm.

# 6. Conclusion

The study on vernacular structures has demonstrated their strength in many aspects. Their resilience has helped them sustain in odd locations and difficult seismic conditions. The traditional knowledge of indigenous people based on various earthquake experiences has helped in construction of refine structures.

Areas of high seismicity have relatively less population (usually rural) and less development. After the disaster such areas are inaccessible, and post disaster help does not reach on time properly and are last to receive the post disaster help. Such vernacular houses even if damaged are easy to rebuild and cost effective. Thus the traditional wisdom of building earthquake resilient houses exists in such places, so that they are self sustained during any calamity.

Vernacular structures have evolved over time depending upon the functional need, availability of materials and influence of modern techniques. These modifications have either helped in increasing their resilience or made them more vulnerable. The evolution vulnerability index (in Chapter 3) thus shows that how a change in building parameter influences the resilience of the structure.

The physical change in the built environment is happening rapidly. Population growth and development are at fast pace. This is increasing the risk of life loss and building damage and also the traditional knowledge of building is lost. Result of risk assessment of Himachal Pradesh districts lying in Kangra source zone shows that Kangra and Mandi district will suffer maximum loss (Chapter 4). Both districts have hilly terrain yet modern construction is intruding the difficult mountainous environment where once only vernacular structures survived. This is also happening because of the unavailability of buildable land. These modern constructions without proper techniques, as that of vernacular structures, are at high risk in earthquake scenario. It is thus necessary to incorporate measures learned from vernacular techniques. Land use planning of new settlements and measures at building level based on vernacular approach can help in building resilient communities. For sub urban and rural areas the vernacular construction can be promoted through capacity building.

# Future Scope Of Work

Vernacular structures at many regions are losing their resilient characteristics because of no proper maintenance and modern construction overshadowing them. It is thus necessary to restore and preserve these structures so that they remain example of resilience for generations to come.

Few traditional building techniques have been recognised by the authorities after their better performance during major earthquakes. For example: after 2005 Kashmir earthquake, the Dhajji Dewari technique was approved by Earthquake Reconstruction and Rehabilitation Authority (ERRA, govt. of Pakistan) and was promoted during reconstruction. Similarly, Bhunga houses of Gujarat built with compressed stabilized earth blocks were approved by government through GSDMA, 2003 because of their good performance during 2001 Bhuj earthquake. Other vernacular techniques should be researched, recognised and promoted as well.



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