Earthquake Vulnerability Assessment of House Constructions in Himalayas

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Abstract

The entire Himalayan range is highly prone to earthquakes and the latest Kashmir earthquake (October 08, 2005) has once again drawn our attention to the highly vulnerable Himalayan settlements. Narendranagar block of the Himalayan state of Uttaranchal lies in seismic zone IV of the seismic zoning map of India. Like in other hilly areas Narendranagar block also witnessed the traditional practice of house construction being replaced by modern construction materials and practices without the knowledge of earthquake resistant techniques rendering the present buildings more vulnerable to earthquakes. The objective of this paper is to assess the vulnerability of the buildings so that corrective measures can be taken to minimize the destruction during future earthquakes. Types of buildings observed in the entire block with different combinations of materials and their earthquake behaviours are explained. The existing structures are grouped into vulnerability categories V1, V2 and V3 as per the descriptions provided in the MSK (Medvedev – Sponheaer – Karnik) Intensity Scale. Damage estimation for a hypothetical earthquake is carried out for the Narendranagar block. Conclusions and recommendations suggesting use of such studies in all earthquake prone areas of the Trans Himalayan region are provided.

Key Words: Earthquake, Vulnerability, Resistance, Risk, Construction typology.

Introduction

Earthquakes are considered to be one of the most dangerous and destructive natural hazards. India has a large part of its land area liable to wide range of probable maximum seismic intensities where shallow earthquakes of magnitudes 5.0 or more on Richter scale, have been known to occur in the historical past. About 56% of the total area of the country is vulnerable to seismic activities of varying intensity (NCDM, 2001). Most of the vulnerable areas are located in Himalayan and sub-Himalayan regions, Kutch and Andaman Nicobar Islands.

As we know, vulnerability assessment is a very important aspect and first step towards earthquake protection. If neglected, this aspect makes our disaster management plan superficial and unrealistic. Hence, there is need for vulnerability assessment at micro level which would result in formulation of appropriate measures for reduction of earthquake disaster (Shankar and Gupta, 2005). The objective of this paper is to assess the vulnerability of Himalayan settlements due to earthquakes because of the construction technology prevailing in the region.

Study Area

The entire Himalayan belt lies between zone IV and zone V of the seismic zoning map of India (BIS, 1893-2002). Narendranagar block of Tehri Garhwal district in Uttaranchal

State of Himalayas is chosen for vulnerability assessment of human settlements (Figure 1) due to several reasons. These are: It lies in seismic zone IV, that is the second most vulnerable of all zones identified on Seismic zoning map of India (BIS, 1893-2002). Earthquakes of damage potential more than MSK VIII and accelerations of 0.25g can be expected in this region. Narendranagar block lies within the most vulnerable zone on the seismic micro-zoning map (Sinvhal et.al., 1990 and 1991). Narendranagar block is prone to earthquake effects like landslides, ground fissures, damage to human settlements, casualties and injuries (DMMC, 2003a and DMMC, 2003b). Narendranagar block has the second highest population density in Tehri Garhwal district. A population of 73,129 is spread in 213 villages (District Statistical Handbook, 2002).

The information required for earthquake vulnerability assessment of prevailing constructions in the block is collected through several field visits and collection of relevant secondary data.

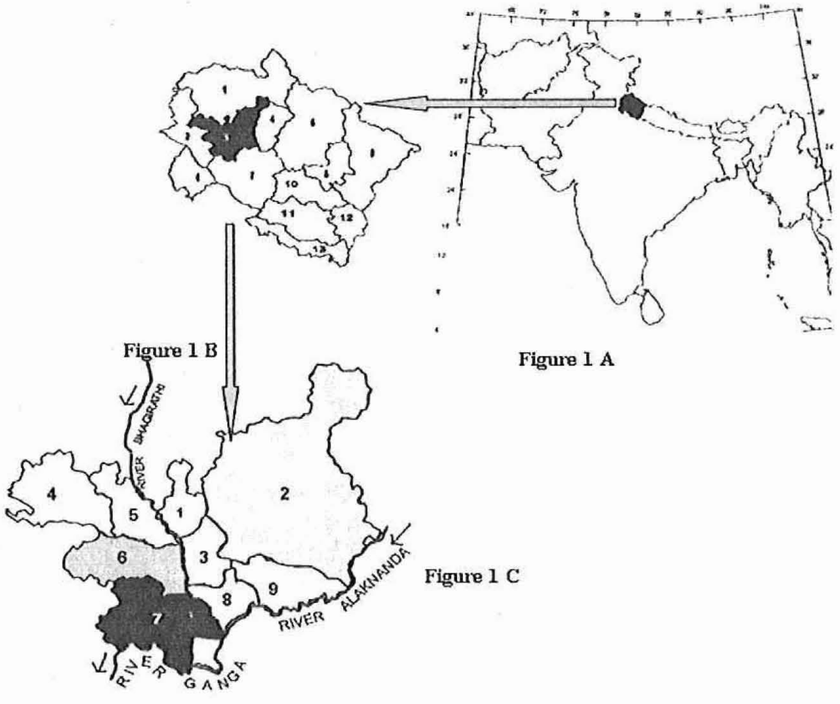


Figure 1

A: Location of Uttaranchal in Map of India
B: Location of Tehri Garhwal district in Map of Uttaranchal. (1- Uttarkashi, 2- Dehradun, 3- Tehri Garhwal, 4- Rudraprayag, 5- Chamoli, 6- Haridwar, 7- Paudi Garhwal, 8- Bageshwar, 9- Pithoragad, 10- Almoda, 11- Nainital, 12- Champawat, 13- Udhamsingh Nagar)
C: Location of Narendranagar block within Tehri Garhwal district. (1- Pratapnagar, 2- Bhilangana, 3- Jakhnidhar, 4- Jaunpur, 5- Thauldhar, 6- Chamba, 7- Narendranagar, 8- Devprayag, 9- Kirtinagar)

House Design

Villages of Narendranagar block are located on quiet mountains of Garhwal Himalayas. Agriculture is the main occupation; hence, these villages are located on comparatively low slope regions for the benefit of terrace farming. Areas of steep slopes are not occupied by villages. Houses are small and simple, built in continuous rows which increase the risk of earthquake damage (Figure 2). They are mostly single storeys but in many places double storey houses are also seen. The rooms of houses are usually small and placed in row. All rooms have at least one external door. In many houses there is no internal connection in the rooms. Floor height in general is small (about 1.8 - 2.4 m). The open space in front of the rooms is used as a utility space for household works. The sheds for cattle are usually located below the house on ground floor, adjacent to the house or in some cases near the house (Figures 3, 4).

Figure 2:
Aerial view of village Kharsad of Narendranagar block

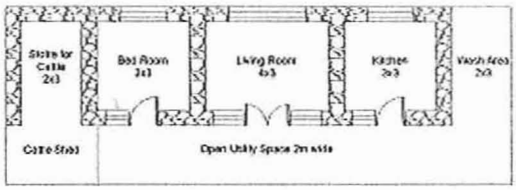


Figure 3C

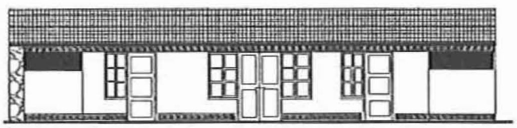


Figure 3 A

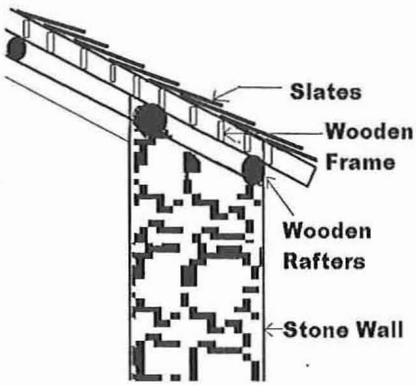


Figure 3D

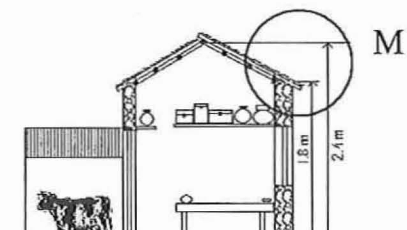


Figure 3 B

Figure 3: (Not to Scale)

A: Front elevation of a typical single storey house, B: Cross section of a typical single storey house
C: Plan of a typical single storey house
D: Detail at M

Figure 4A

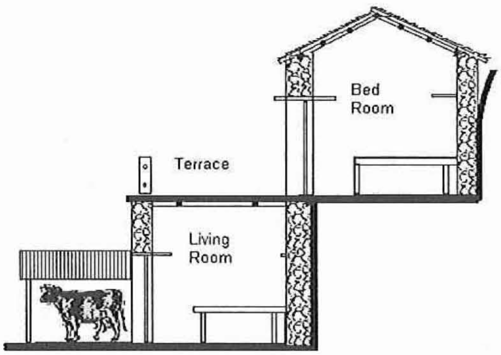
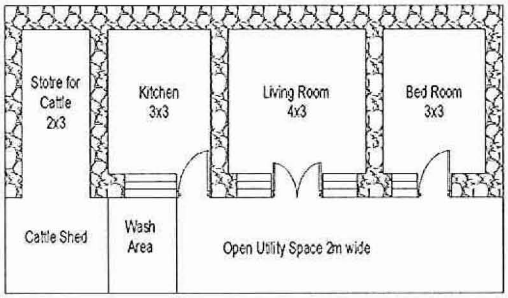


Figure 4B



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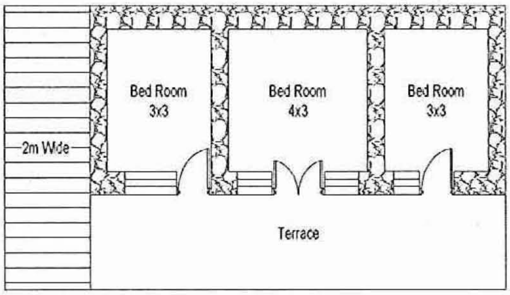

Figure 4D

Figure 4:

- A: Front elevation of a typical double storey house
- B: Cross section of a typical double storey house
- C: Ground floor plan of a typical double storey house
- D: First floor plan of a typical double storey house

Construction Technology

In earlier times the building material used in the region were locally available long thick wooden logs, stones, slates and clay. The judicious use of all these had made those constructions earthquake resistant. This traditional practice of house construction is now been replaced by modern construction practices and technology. This is because of various reasons, the main one being increasing restrictions imposed due to environmental protection. A traditional right to felling of trees has been curbed, which has led to its scarcity, growing demand and increase in price due to these and transportation costs. Quarrying of stone has also met the same fate (Rautela, 2005). These days, majority of buildings are box type, load bearing stone, brick or concrete block masonry. The seismic performance of load bearing masonry structures depend heavily on the structural characteristics (strength, stiffness and ductility) of surrounding walls and roofs. They rely on walls to resist in-plane and out-of-plane inertia forces and on the roofs for resisting the shear forces and to distribute the forces to vertical elements (walls) and maintain the integrity of structure. A critical appraisal of seismic resistance of widely practised construction techniques in the region is presented here.

Wall Constructions

It was observed that the predominant walling material used in the region is stone followed by bricks. Earth walls are also seen although rarely. In some cases mixed constructions are seen, where extensions in original stone walls are made with brick walls.

Stone masonry walls: Common rock types which are used for wall constructions are sand stone, limestone, quartzite and slate, which are internally very durable building materials. Some positive features of stone buildings are given below (BMTPC, 1992):

- Most abundant local material does not require much transportation to building site.
- Good insulation from cold due to large wall thickness
- Very durable and fire resistant

Defects of stone buildings:

- Weak in tension and shear; the unstable configuration of stones when shaken from initially constructed position makes the wall collapse due to heavy vertical loads.
- Very weak bond between walls at right angles to each other leads to very easy separation of walls.
- Delamination of wall into separate outer and inner walls due to absence of bond stones.
- Easy shattering and collapse of stone gables.

Different forms of stone masonry which have shown varying degree of performance in the past earthquakes are given below:

Stone in mud mortar: In Narendranagar block, rubble stone in mud mortar is the most common walling material (dressed stone in mud mortar is also rarely used). The walls thus constructed are generally 450-600 mm thick. In general, the quality of wall construction is not good: there is no positive bond between walling units of each wythe and also between the wythes. As a general practice, through stones are not used, and the gap between wythes is filled with small stone pieces and mud. The resulting thin slender wythes behave as independent members, without any structural connection between the external and internal wythes. (Figure 5).

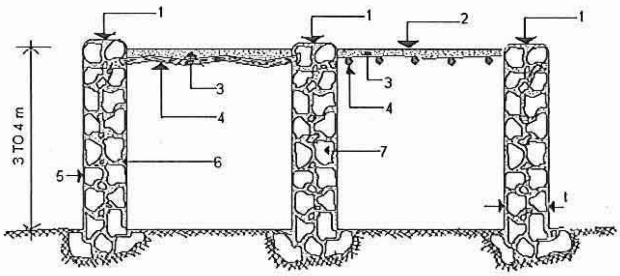

Figure 5 A

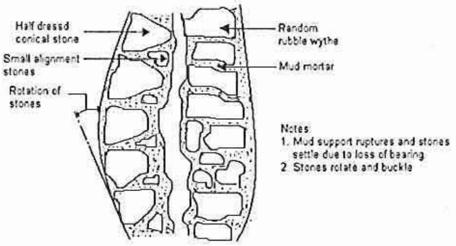

Figure 5 B

1 – Stone wall with mud mortar
2 – Mud fill at roof and floor 150 to 300 mm thick
3 – Branches, reeds
4 – Log beams
5 – Hammer dressed face
6 – Chip and mud filling
7 – Random rubble
t – Wall thickness 0.6 to 0.9 m

Figure 5 (Source: ISET, 2001)
A: Schematic cross section through a traditional stone house,
B: Wall delaminated with buckled wythes.

The stone masonry prevalent in the Narendranagar block can be grouped in the following two categories based on construction forms.

Stone and slate masonry: As seen in old houses, traditionally, the stone masonry is made up of large sizes of stone blocks laid in mud mortar. Many thin wafers of slate are filled in the depressions of large stones to create an "even" course and finished outer (exterior) surfaces (Figure 6A). The wall thickness can vary from about 450 to 750 mm consisting of two wythes. In well constructed houses where quality of workmanship is good, through stones are used frequently to bind both wythes.

The damage to such masonry in past earthquakes had been moderate to less, depending on the quality of masonry and workmanship. Many layers of jointing material (mud mortar in most cases) provide a very large area for accommodating relative movements between masonry units (stone boulders and large number of thin slates) during the ground shaking and thus, dissipating energy through friction and material hysteresis. Furthermore, even weak mortar provides large lateral shear resistance through adhesion from large surface area available from many layers of jointing. However, its use has been declining because it is very time consuming to lay thin layers of slate. As a result, very few and thicker slates are being used with much larger pieces of stone and in some cases, the mud mortar is being replaced with weak cement – sand mortar which has helped in many cases. (GSI 1992 and NSET and DEQ 2000).

Random Rubble (R/R) stone masonry: In general, Random Rubble (R/R) stone masonry has no layers of slates to fill in the undulating contours of large stones. These walls are composed of two wythes with total wall thickness varying from 450 to 750 mm. undressed stones are laid in mud mortar and plastered in cement – sand mortar to provide finished surface. (Figure 6B)

Such structures, especially the older ones have suffered heavy damages during the past earthquakes.

Stone in Cement Sand Mortar: Cement – sand mortar is not common for stone masonry: only a few government buildings, urban area dwellings and those along highways can be seen constructed with stone masonry laid in cement – sand mortar. Walls are thick up to 450 mm and the mortar mix is 1:6 or leaner. Floor and roof of these buildings are generally, cast in situ RC slab. (Figure 6C)

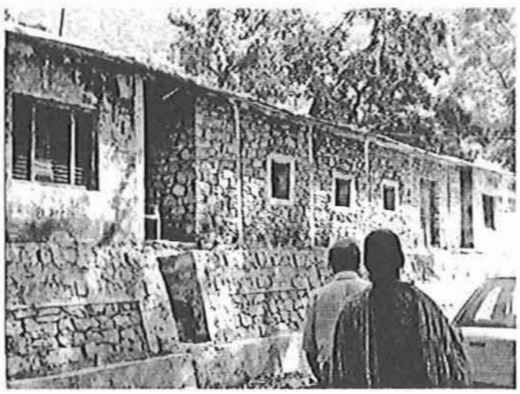

Figure 6: Stone walls
A: Stone and slate masonry
B: Random rubble stone masonry with cement plaster
C: Stone in cement sand mortar with cast in situ RC slab

Clay Brick and Concrete Block Masonry Walls: Fired brick and cement concrete blocks are rather new building materials in the area. These walling units are laid in cement- sand mortar and are used in load bearing as well as infills in weak RC frame construction. Their recent use appears to have been encouraged by Uttarkashi (1991) and Chamoli (1999) earthquakes, where stone masonry walls have shown poor performance and were responsible for larger number of deaths. In general, wall thickness is 230 mm in case of brick units and 200 mm in case of concrete block. These buildings often have been provided with lintel and roof bands (Figure 7). Brick masonry is not only used for small dwellings but also for schools, shops, dispensaries and other community buildings. Concrete blocks are made from cement, sand (fine stone powder, when sand is not available in high reaches) and coarse aggregate in various dimensions. Typical dimension being approximately 300 mm X 225mmX 150 mm. Many factors have contributed to growing usage of concrete blocks such as unavailability of new quarries, time consuming and labour intensive activity of laying stone and slate masonry uneconomical due to large quantity of cement – sand mortar required per unit volume of masonry, transportation of clay bricks from the plains, and in general, poor performance of stone masonry.

Positive features of such buildings are:

- Durable construction with minor levels of maintenance
- Comfortable interiors, reasonable insulation against heat and cold
- Resistant to rains and flooding
- Fire resistant
- Well constructed and integrated wall enclosures provide good stability against vertical as well as lateral loads.

Defects in the burnt brick or concrete block buildings

- Poor strength of material in tension and shear, particularly where mud mortar or lime – sand mortar weaker than 1:3 or cement mortar weaker than 1:6 is used.
- Toothed joints cause a vertical plane of weakness between perpendicular walls.
- Large openings and their placement too close to the corners can cause failures
- Very long rooms having long walls unsupported by cross walls fail in bending or overturning.
- Unsymmetrical plan of building, with too many projections. (BMTPC, 1992)

The performance of these buildings during earthquakes is related with the type of roof, the mortar used and the quality of construction. Performance has been poor with pitched roofs having no binding effect on walls, poorer with mud or weak mortars and still poorer with bad quality construction. Buildings with rigid slab roofs have generally behaved much better than others due to their binding effects on walls by diaphragm action by which lateral load is transferred to shear walls. Cracking is frequently observed in diagonal or cross form in the masonry piers between the openings (since clay bricks are much weak as compared to stones), vertical cracks near the corners leading to separation of perpendicular walls through toothed joints and horizontal bending cracks in the walls which are at right angles to the predominant direction of the earthquakes. Also, very minor damage to concrete block masonry walls was observed. (GSI 1992 and NSET and DEQ 2000)

Earth walls: Earthen walls are not common in the block and are usually seen in the very remote villages. The basic material for earth construction is well graded earth compressed in soil-block pressed or rammed in wooden forms. Locally available soil is used with or without admixtures like chopped straw or cement.

For one storied houses the walls are from 230 – 350 mm thick in compressed blocks and adobe, 400 – 500 mm thick for rammed earth. The room sizes are usually of small dimensions upto 3m X 5m in plan particularly when pitched roofs are used (Figure 8). A variation of earth houses are pitched roof of thatch or slate supported on independent wooden posts on the outer side of the walls.

Positive features of earth buildings:
- Cheap initial and energy costs, particularly if constructed through self help community activity.
- Good thermal insulation against cold and fire resistance.
- Wooden wall plates in continuous runner form provide integrity to the enclosures as a box against lateral forces.

Defects of earth buildings
The main weaknesses and defects of earth houses are:

- Poor strength of material in tension and shear.
- Poor bond between walls meeting at right angles.
- Large openings being too close to the corners.
- Small bearing length of lintels across openings. (BMTPC, 1992)

The performance of earth houses during earthquakes of MM VII or more has been generally poor: wide cracks in the walls and separation of walls at corners. Complete collapse of walls, roofs and floors leading to death and injury to the residents are also common. Due to heavy mass of debris, the rescue of buried people has also been difficult. (GSI, 1992 and NSET and DEQ, 2000)

Roof constructions

The materials for roofs are mainly slate, timber, mud, RCC and thatch. CGI sheets are used at some places for cattle sheds etc. Flexible roofs like slate roofs, thatch roofs etc are inherently weak in shear and can not tie the walls together even when they are properly connected to them. Most of roof failures can be attributed to a combination of deficiencies such as loss of support of roof trusses and rafters due to failure of masonry walls and failure of roof itself due to failure of joints and / or members forming the truss or other roof supporting structure. Rigid roofs like flat, cast-in-situ reinforced concrete slabs are recent substitute for old fashioned pitched roofs and wooden flooring systems. Mixed constructions are also seen in some cases, where extensions in original slate roof houses are made with RCC roofs. (Figure 9)

Slate roofs: Slate roofs are the most popular roof types in the hilly area. People prefer this roof type because of easy availability of material and their inherent knowledge of repair and maintenance of these roofs. Slates are easily reusable and a market for recycled slates exists, especially among the poorer households. These roofs are composed of slates over timber frame which gives them flexibility to certain extent. Slates are most common roofing material which is typically about 25 – 50 mm thick depending upon local availability. Slates are laid on 50 – 75 mm thick layer of mud to keep weather out. Mud is laid on fire wood or planks supported by beams generally spanning gable to gable wall. Slates are not tied up with structure. In some buildings wooden planks are placed on rafters to support the roofing material. They are heavy attracting large inertia forces and often slates were observed to be dislodged even when the roof supporting structure survived the shaking. (GSI, 1992 and NSET and DEQ, 2000)

During past earthquakes the local people found that the slate roofs often collapse in segments, allowing people to escape relatively easier than when they were pinned under an RCC slab. (BMTPC, 1992)

Thatch roof: These roofs are constructed of thatch with timber frames. They are always used over small sized rooms with stone or earth walls. They are used for very poor households or cattle sheds. (Figure 10)

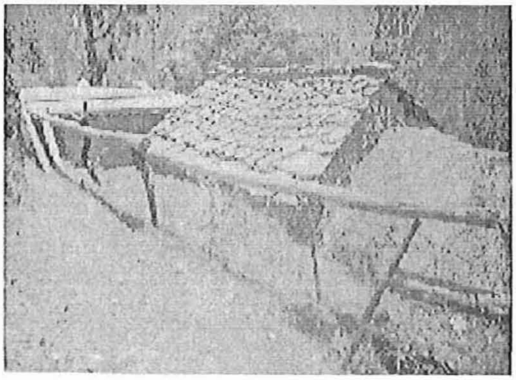

Figure 9: Mixed roofs (RCC, Slate and Thatch)

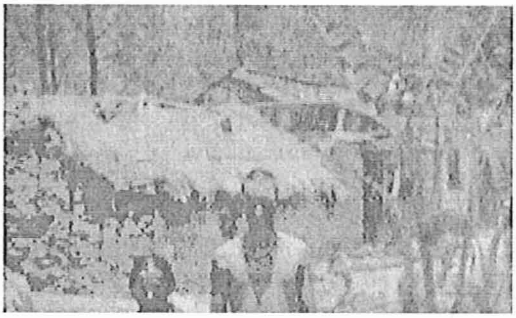

Figure 10: Thatch Roofs

CGI sheet roof: These roofs are composed of CGI sheets mounted over timber frames. These are mostly used for non-residential use like cattle sheds, small shops along roadside etc.

Floor Diaphragms: Floor diaphragms are usually constructed of mud laid on wooden planks or firewood supported by timber joists. Joists at ends simply rest on the wall without any anchorage or tie. Moreover, in general, the joists do not fully penetrate the entire wall in order to protect it from rain.

RCC roofs: The quality of RCC roof construction was found to be bad, largely because of low quality materials and lack of knowledge of RCC technology. Stone aggregate and sand is dirty, badly graded and aggregate often contains rounded stones. Water cement ratios are not maintained. Slabs are typically over reinforced and supporting columns under reinforced, with inadequate bar spacing. Cover is rarely maintained and tamping is inadequate leading to exposure of bars and voids in the concrete. The net result is that a large number of slabs leak and the reinforcement corrode. The local solution is to use bitumen tar to fill the cracks.

Light Reinforced Concrete (RC) Frame

RC buildings are present particularly in urban areas. They are gaining popularity because of better utilization of space and general perception that these are "stronger". However, most of the framed buildings are non-engineered. They typically consist of a weak RC frame, that is, at most capable of carrying vertical gravity loads, and infilled walls of brick or concrete block in cement sand mortar. The construction of frames can both precede and follow the construction of masonry infill walls.

Frames are usually light with column size 230X230 mm with four to six number of 12 mm diameter reinforced bars (Fe 415). Even use of 10 mm diameter bars was also observed. Stirrups are typically 6 mm diameter bars at 200-250 mm spacing. The columns spacing in each principal direction of the building varies from 3 to 4.5 m. It is usual to have shops on the ground floor, with large openings on one or adjacent faces. In most cases floor heights are about 2.7 m, but occasionally are up to 3.0 m. Floors and roofs are constructed of cast-in-situ RC slab (Figure 11).

Performance of these buildings during earthquakes is more like hybrid structures, where infills play a major role in resisting seismic loads, especially before the cracking of masonry. Frame action is only possible when the infill masonry is cracked and lost its strength and stiffness considerably.

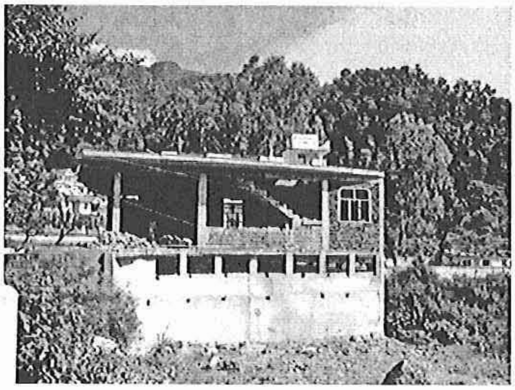

Figure 11:
RC Frame construction in Tapowan

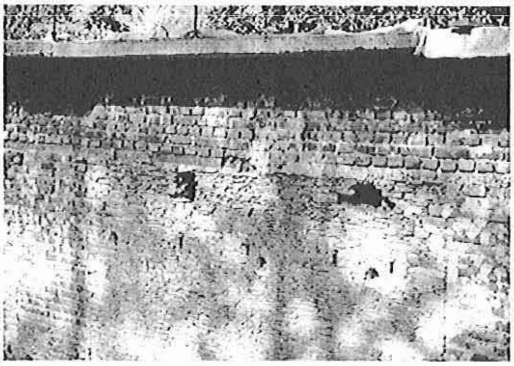

Figure 12:
Composite wall construction of slate and bricks

Composite Constructions

These are type of construction with mixed features. The outer face of the wall is built in burnt bricks laid in mud mortar, the inner is built from unburnt bricks or adobe. This although seen very rarely, is a better quality construction than traditional adobe one. The outer layer protects the wall from erosion during the rain and helps in carrying part of the vertical loads of the upper floors and roof.

The composite constructions are also seen for same houses where different set of building materials and construction technology is used. These are essentially extensions in the original construction with more modern materials and construction practice. (Figure 12)

Vulnerability Analysis of the Constructions

All types of constructions seen in the block are categorized into three vulnerability categories ranging from most vulnerable to least vulnerable. This categorization is done on the basis of descriptions provided in the MSK intensity scale (Medvedev – Sponheaer – Karnik Intensity Scale, 1964). (Table 1, Table 2)

Table 1: Vulnerability category and descriptions of constructions in Narendranagar block as per MSK scale

Vulnerability category	Description	Description as per MSK scale
VI	Low	Reinforced buildings, well built wooden structures.
V2	Moderate	Ordinary brick buildings, buildings of the large block and prefabricated type, half timbered structures, buildings in natural hewn stone.
V3	High	Buildings in field – stone, rural structures, adobe houses, clay houses.

Table 2: construction types with different wall and roof combinations, categorized as per MSK scale

Walling Material \ Roofing Material	Slate roof	Others (thatch, timber, CGI)	RCC	Composite
Stone and slate masonry in mud	V3	V3	V3	V3
Random rubble Stone masonry	V3	V3	V3	V3
Stone in cement Sand mortar	V2	V2	V2	V2
Clay Brick / Concrete block masonry	V2	V1	V1	V2
Earth walls	V3	V3	V3	V3
Light Reinforced Concrete Frame	V1	V1	V1	V1
Composite (Stone and Brick)	V3	V2	V2	V3
Composite (timber and stone)	V3	V2	V2	V3

However, vulnerability category can change for various buildings depending on other factors like:

- Improper stilt construction on the slopes,
- Construction of upper story on weak lower stories,
- Absence of proper joints in composite constructions breaking the integrity ofstructure,
- Dangerous locations.

Earthquake Hazard

The close proximity of three mega thrusts in Narendranagar block (Jain, 1987) coupled with the fact that the river Ganga winds in a sinusoidal manner in this area plus the presence of more than 270 micro earthquake epicenters (EQ 86-2, EQ 87-16) in the time frame of 5 years indicates that tectonic stresses are building up in this area. This could be a possible location of a medium to large sized earthquake in the future. The point of inflexion of the Ganga River, which coincided with the micro zone D3 (Sinvhal et.al. 1990, 1991), seems to be the candidate area for an earthquake scenario. A hypothetical epicenter is considered near Tapowan at 30^0 08'10"N and 78^0 20'30"E. Destructive earthquakes in the lower Himalayas are in the magnitude range 6 – 8. Earthquake hazards in any region are best estimated by peak accelerations. These were computed (McGuire 1977) for earthquakes of magnitude 7.0 and 7.5 for different hypo central distances, to cover the entire Narendranagar block (Table 3). The highest peak accelerations for magnitude 7.0 and 7.5 computed for a hypo central distance of 20 kilometers are 0.30 cm / sec^2 and 0.41 cm / sec^2 respectively. This is significantly higher than what is expected to occur in seismic zone IV, 0.25 cm / sec^2. This implies that in Narendranagar block earthquake damage can be expected to be much higher than what is expected as per the seismic zoning map of India. Iso-acceleration contours with these hypothetical earthquake scenarios were plotted for different hypo central distances. The contours were subsequently elongated parallel to the trend of Main Boundary Fault to account for regional tectonics. (Figure 13) (Gupta et.al., 2006)

Table 3: Peak accelerations for earthquakes of magnitude 7.0 and 7.5 for different hypo central distances. (Source: Gupta et.al., 2006)

Hypo-central distance (km)	Peak accelerations (cm / sec^2)		Area (Sq. Km)	Length of Axis (km)	
	Mag 7.0	Mag 7.5	Long Axis	Short Axis	
20	0.309	0.410	1257	50	20
25	0.269	0.365	1964	66	28
30	0.249	0.325	2828	82	36

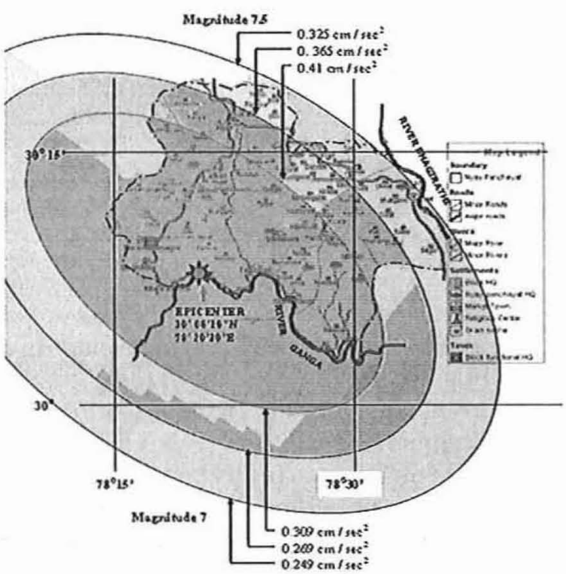

Figure 13:
Acceleration contours with epicenter at Tapowan (30^0 08'10"N and 78^0 20'30"E) for different hypo-central distances elongated parallel to the trend of Main Boundary Fault. (Source: Gupta et.al., 2006)

Methodology adopted for damage assessment:

1. During pilot studies in eight villages of the selected region, it was found that the accessibility condition of the villages is the influencing factor on the construction technology. Hence all villages were grouped on the basis of accessibility conditions into five different categories and three villages from each category i.e. total fifteen villages were surveyed for detailed studies.
2. The approximate percentages of three types of constructions (V1, V2 and V3) are calculated in all sample villages through field visits. The average calculated is considered typical for all villages under the same accessibility category. Hence, number of structure types in all villages are calculated using MS Excel software.
3. The iso-acceleration contours drawn are converted into intensity contours using the conversions (Bolt B. A. 2000 and Reiter 1990). As observed and proved from the experiences of past earthquakes, the intensity in a valley may be 1 – 2 scales lesser as compared with the crest of mountains (GIS 1992). Expected intensity of each village is calculated considering this topographic effect, which varied from VII to IX on MSK scale.
4. Numbers of buildings with different grades of damage are calculated village wise from the damage descriptions and quantifications provided in the MSK Intensity scale.

Results

The damages to the buildings as a result of this are grouped into five categories, ranging from no damage to total collapse. (Table 4)

Table 4: damage to the house buildings of the Narendranagar block

Damage category	Description	Number of buildings in villages	Number of buildings in towns	Total Buildings	Percentage
G1	No damage	1490	1089	2579	12.36
G2	Minor damage	3904	2393	6297	30.18
G3	Moderate damage	4804	1979	6783	32.51
G4	High damage	3137	992	4129	19.79
G5	Collapse	887	187	1074	5.16
	Total	14222	6640	20862	100

Hence, it is known that almost 58 percent of house buildings of Narendranagar block are at risk of facing moderate to heavy damages. This risk increases if the earthquake magnitude is larger, and may be even higher in the vicinity of faults, riverbeds, intersection of fault and river and in the areas of higher population.

Conclusions and Recommendations

The geological investigations suggest that Narendranagar block can experience a damaging earthquake at any time. Since the construction technology existing in any region is responsible for the severity of hazard, the methodology suggested in the paper to determine earthquake risk of the region, can act as pioneer study for risk assessment. These studies can also lead to estimation of casualties and injuries i.e. human risk (Coburn and Spence, 2002). This exercise of risk assessment when carried out for different earthquake prone regions would contribute directly and substantially to preparedness measures and emergency response capabilities. The resulting recommendations can help in taking corrective measures for reduction of disasters in the region.

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