Reconnaissance Report

Chamoli Earthquake of 29th March 1999, India

Joint Study by NSET-Nepal and DEQ-UOR, India

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PREFACE

The devastating Chamoli earthquake of 29th March 1999 affected parts of the Alaknanda and Mandakini valleys of Garhwal Himalayas, India. The tremor was felt in seven districts of Far-western Nepal, where damages to houses were reported. Considering the similarity of building typologies in the affected regions of India and Nepal, and the possibility of learning from the natural event towards improving mitigation capabilities and methods, NSET-Nepal and the DEQ-UOR entered into a collaboration arrangement for a joint study of the damages due to the earthquake. Such study was regarded of high importance in view of the ongoing implementation by NSET-Nepal of the Kathmandu Valley Earthquake Risk Management Project (KVERMP) as a Nepal Demonstration Project under the Asian Urban Disaster Mitigation Program (AUDMP) of the Asian Disaster Preparedness Center (ADPC), with core funding from USAID / OFDA. As a component of KVERMP, NSET-Nepal is implementing the School Earthquake Safety Program that seeks to assess structural vulnerability of the buildings of about 643 public schools of Kathmandu Valley.

USAID / OFDA provided funds to NSET-Nepal for undertaking the study jointly with the DEQ-UOR, Roorkee, India. Dr A. S. Arya provided consultancy to this study project.

A joint study team with the following composition conducted the study:

Nepalese Team Members

Mr. Jyoti P. Pradhan, DDG, HMG / N Department of Buildings
Dr. Min B. Poudyal Chhetri, US, HMG / Nepal Home Ministry
Mr. Jitendra K. Bothara, Structural Engineer, NSET-Nepal
Mr. Basant Kafle, Seismologist, Department of Mines & Geology
Mr. Ram Chandra Thapa, Junior Engineer, NSET-Nepal

DEQ-UOR Team Members

Dr. Durgesh C. Rai, Assistant Professor
Dr. J. P. Narayan, Assistant. Professor

The entire team visited the earthquake affected region in India, whereas Dr. Min B. Poudyal Chhetri and Mr. Jitendra K. Bothara visited the earthquake affected areas in Nepal.

Shiva Bahadur Pradhanang
President
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We express our gratitude to Prof. Navin C. Nigam, then Vice Chancellor, University of Roorkee, Roorkee for collaborating in this study, and to Prof. S Basu, then Head, Department of Earthquake Engineering, University of Roorkee, for the cooperation and understanding received. We highly value the importance of such cooperative arrangement that allowed institutions in the region to learn from the rich experience of such reputed center as the Department of Earthquake Engineering, University of Roorkee (DEQ-UOR), Roorkee, India.

We are also thankful to Mr. T. N. Gupta, Executive Director, BMTPC, Ministry of Urban Development, Government of India (GOI) and Mr. Santosh K. Taneja, Chief, Building Materials Technology, Housing and Urban Development Corporation, New Delhi, India, for sharing their rich experience in the field of earthquake damage assessment, mitigation and response.

Mr. Kulwant Singh, Councellor, Indian Embassy, Kathmandu, Nepal heartily supported the collaborative arrangement between the two institutions of Nepal and India. He encouraged NSET-Nepal for taking the initiatives and facilitated the study with timely clearance of all formal procedures for the Study. We express our sincere gratitude to him.

We extend our sincere thanks to Prof. A. S. Arya, Professor Emeritus, DEQ-UOR, for his support in the overall planning of this project. He effectively facilitated the contacts with various officials and organizations that went a long way in the successful completion of the study including the fieldwork in Chamoli area.

We are also indebted to the Office of Foreign Disaster Assistance (OFDA) of the US Agency for International Development (USAID) not only for providing the funds for the study, but also for their sustained support to NSET-Nepal.

Grateful acknowledgements are also due to the various officials and the people of the affected area, who provided all cooperation to the joint study team despite being extremely busy in the noble task of providing assistance to the affected. Efforts of Mr. Tana Gautam, Mr. Baman P. Neupane, Mr. Sthaneshwor Devkota, Mr. Gita P. Khanal, Mr. Bhola P. Siwakoti, Mr. Mohan P. Acharya, Chief District Officers of Banke, Kailali, Kanchanpur, Dadeldhura, Baitadi and Darchula districts respectively of Nepal is also acknowledged for their assistance is arrangement of field survey.

Last but not the least, sincere thanks are due to all members of the joint study team for their excellent fieldwork carried out in a professional spirit.

ACRONOMY

DEQ-UOR-	Department of Earthquake Engineering- University of Roorkee
BMTPC	Building Materials Technology Promotion Council
GOI	Government of India
OFDA	Office of the Foreign Disaster Assistance
MBT	Main Boundary Thrust
MCT	Main Central Thrust
MFT	Main Frontal Thrust
HUDCO	Housing and Urban Development Corporation
CGI	Corrugated Galvanized Iron
VDCs	Village Development Committee
CBRI	Central Building Research Institute

EXECUTIVE SUMMARY

A moderate earthquake, 6.8 on Richter scale, in Garhwal Himalayas rocked the cities of Chamoli, Gopeswhar and Rudraprayg in India and affected parts of Kanchanpur, Dadeldhura, Baitadi and Darchula districts in Nepal on March 29, 1999 at 00:35:13.4 hours IST. The epicenter of this even was located at 30.408 °N, 79.416 °E near Chamoli/Gopeshwar. The focal depth for the event was estimated as 21 km. The maximum peak ground acceleration (PGA) of 0.359*g* was recorded at Gopeshwar, the nearest accelerograph station from the epicenter at a distance of about 10 km.

As most of the damage due to the Earthquake was in India, a greater part of the description in this report belongs to Indian cities and village areas. Wherever felt important, description has been provided for the affected areas of Western Nepal also

The maximum intensity assigned to Chamoli earthquake is VIII- on the MSK scale, which caused the loss of about 100 human lives and rendered 100,000 people homeless. Severe damage were concentrated in an elliptical area (50x20 km), particularly near the apex of the major axis. The elongation and orientation of the isoseismal line for intensity VII reveals rupture may have occurred on a low angle fault in WSW-ENE direction. It has also been concluded on the basis of damage survey that the local site conditions, such as strong lateral heterogeneity, soil cover and topography of the area have played major role in the damage pattern.

Most of residential units in the affected area relied on load bearing masonry walls for seismic resistance. Much of the damage could be attributed to ageing, inferior constructions materials, inadequate support of the roof and roof trusses, poor wall-to-wall connections, poor detailing work, weak in-plane wall due to large openings, out-of-plane instability of walls, lack of integrity or robustness and asymmetric floor plans. The extent of damage would have been drastically reduced had modern earthquake-resistant design procedures and construction practices been followed.

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1. Definition of damage grades
2. List of the persons met and consulted during the study

CHAPTER 1. INTRODUCTION

1.1. GENERAL

This is a Reconnaisance Report on the survey of various aspects of damage due to the Chamoli Earthquake that struck Garhwal Himalayas on 29th March 1999 at 00:36 IST. The earthquake resulted in a heavy loss of human lives and damage to property.

The study was organized by the National Society for Earthquake Technology - Nepal (NSET-Nepal) in collaboration with the Department of Earthquake Engineering, University of Roorkee (DEQ-UOR), Roorkee, India. Field survey for the study was carried out by a joint team of Nepalese professionals and faculty members of DEQ-UOR, India. Funding for the study was obtained from the Office of the Foreign Disaster Assistance (OFDA), USAID, Kathmandu, Nepal.

The Nepalese team included Mr. Jyoti Prasad Pradhan, Deputy Director General, Department of Buildings; Dr. Min Bahadur Poudyal, Under Secretary, Ministry of Home; Mr. Jitendra K. Bothara, Structural Engineer, NSET-Nepal; Mr. Ram Chandra Thapa, Junior Engineer, NSET-Nepal; Mr. Basant Kafle, Seismologist, Department of Mines & Geology. Faculty members of DEQ-UOR included Drs. Durgesh C. Rai, and J. P. Narayan. Mr. Jyoti Prasad Pradhan led the team. The team surveyed the earthquake-affected areas from 29th April to 5th May 1999.

The Nepalese members left Kathmandu, Nepal on 26th April 1999 and joined the Indian members of the team in Roorkee on 28th April. The joint team departed on 29th of April for Chamoli. Field survey in the valleys of Alaknanda and Mandakini rivers of India was carried out during 29th April to 5th of May 1999. Two members of the team, namely, Dr. Min Bahadur Poudyal and Mr. Jitendra K. Bothara, undertook a field trip to earthquake affected areas in Nepal in June 1999. Location of the surveyed area, and the survey routes in India and Nepal are shown in Figure 1.

1.2. OBJECTIVES OF THE STUDY

The study was conducted with the following main objectives:

- To familiarize the Nepalese team members with the consequences of an earthquake event
- To observe the general effects of the earthquake in various intensity zones
- To look at the damage pattern of buildings, especially the school buildings
- To learn about the system of damage assessment as practiced in India
- To learn about the problems of organizing relief in post-earthquake situation
- To conduct survey/assessment of a few school buildings with the aim of testing the methodology being employed in the School Earthquake Safety program of the Kathmandu Valley Earthquake Risk Management Project (KVERMP) being implemented by NSET-Nepal
- To learn about possible retrofitting/repair methods and their costs, and
- To learn about the approaches of rehabilitation and reconstruction

Additionally, the study envisaged promotion of cooperation between institutions of Nepal and India in aspects of earthquake risk mitigation, and sharing of experiences.

1.3. EXPECTED OUTCOME OF THE STUDY PROGRAM

The followings were the expected outcome of the Study:

- A written document on the lessons learnt
- A presentation to Nepalese professionals and administrators (disaster managers) of Nepal on the effects and the experiences
- Improved knowledge of Nepalese professionals on aspects of earthquake damage assessment, earthquake emergency management
- A report for submission to OFDA, USAID

1.4. SCOPE AND LIMITATIONS OF THE STUDY

The study, especially the field survey, was conducted in a limited time period. Hence, the joint team could not visit all of the area affected by the earthquake. Therefore, this study does not pretend to have covered all aspects of the complex situation resulting from a significant earthquake.

The study was undertaken with the aim of learning from the phenomena rather than to conduct any specific detailed research as intensity mapping. It relied on the scientific data on the earthquake event, as well as on information of emergency response, relief, and rehabilitation on the respective sources of information in India.

Although the study was thus general, it did provide valuable lead to the ongoing vulnerability assessment of school buildings in Kathmandu Valley, Nepal. Study of the damage pattern of the stone-masonry buildings in different intensity zones of the affected area provided important scientific leads for the on-going KVERMP project.

Because of various reasons, study in the affected area in Nepal was conducted only by two of the members of the joint team. Although located very far from the epicentral region, parts of western Nepal did feel the shaking, and several buildings were seriously damaged.

1.5. ORGANIZATION OF REPORT

This report has been organized in the following manner: Chapter 1 is an introduction to the study which describes funding mechanism, the team, objectives, the expected outcomes, and its scope and limitations. Chapter 2 describes in brief the geology and seismotectonics of the region, seismic parameters of the earthquake as obtained from various sources, and characteristics of the strong ground motion. Intensity mapping, isoseismal map, local site effects and the ground deformations associated with the event have been described in Chapter 3. Chapter 4 describes the damages to the building structures with particular reference to variations in construction materials and building typologies in India and Nepal. A brief description of damage to lifelines is provided in Chapter 5. A critical analysis of post earthquake emergency response for rescue and relief is provided in Chapter 6. Reconstruction and rehabilitation effort that followed the earthquake is described in Chapter 7. Finally, major findings of this field study is summarized in Chapter 8.

CHAPTER 2. SEISMICITY AND STRONG GROUND MOTION

2.1. INTRODUCTION

Garhwal-Kumaun Himalaya was rocked by an earthquake of magnitude, Mw=6.8, Ms=6.6, Mb=6.3, on 29th March 1999 at 00:36:13.4 IST. The United States Geological Survey (USGS) located the epicenter of this earthquake as 30.512°N and 79.403°E near Gopeshwar in Chamoli District of Uttar Pradesh, India (Table 2.1). The depth of this earthquake was 21 km as reported by USGS. The maximum intensity of the event was VIII- on MSK intensity scale. Most of the damage was concentrated along the Alaknanda and Mandakini river valleys in the districts of Chamoli and Rudraprayag. This earthquake lies in the highest Seismic Zone V of the Indian Seismic Code (IS:1893-1984). In addition to damage to built environment, this earthquake caused triggering of new landslides, reactivation of known landslides, ground fissures, and rock falls in the epicentral area). The earthquake also caused changes in ground water regime of the affected area as evidenced by drying out of some springs and increase of discharge in others. The fault plane solution of this earthquake shows a dominant thrust component (Table 2.2).

Table 2.1: Chamoli Earthquake Parameters

Agency	Epicenter		Magnitude		Focal Depth	Origin time
	Lat.	Long	Mb	Ms	(km)	(IST)
USGS	30.55	79.424	6.3	6.6	10	19:05:10.00
USGS (Revised)	30.512	79.403	6.3	6.6	15	19:05:11.03
IMD	30.300	79.566		6.8	21	19:05:12.00

Table 2.2: Fault Plane Solution of Chamoli Earthquake (USGS)

	Strike	Dip	Slip
NP1	282	9	95
NP2	97	81	89

2.1.1. Injuries and loss of human lives

The loss of human lives inflicted by the Chamoli earthquake of March 29, 1999 was concentrated in two regions namely: Chamoli town, Mandal valley, Devaldhar valley and the surrounding village of the Chamoli district and Ukhimath as well as Jakholi blocks of the Rudraprayag District. According to the local and national New papers, more than 100 people have lost their lives-59 in Chamoli, 37 in Rudraprayag and 5 in New Tehri town and over 400 people were injured- 150 in Chamoli, 200 in Rudraprayag and 50 in New Tehri districts of the Uttar Pradesh. The details of the casualty are listed in table 2.3. The loss of human lives caused by the Chamoli earthquake was very less as compared with the Latur earthquake (1993), although the quality and the damage to the houses were of same category. This may be due to the thinner population density in the Garhwal-Himalayan region.

Table 2.3. Distribution of casualty (Amar Ujala, March 30, 1999).

District	Village/Town	Casualty		District	Village/Town	Casualty
Chamoli	Lower Chamoli	16		Rudraprayag	Bhatawari	2
,,	Upper Chamoli	10		,,	Kyunja	3
,,	Siro	1		,,	Pingala Pani	3
,,	Devaldhar	2		,,	Makku	5
,,	Gulab Koti	2		,,	Parkari	2
,,	Pakhi	1		,,	Dharkot	2
,,	Brahmsain	2		,,	Lwara	1
,,	Ghighran	1		,,	Taila	3
,,	Badakoti	3		,,	Akhori	2
,,	Pawaldhar	1		,,	Kansili	1
,,	Papadiyana	6		,,	Launga	1
,,	Pipalkoti	2		,,	Naga	2
,,	Nandaprayag	1		,,	Tyokhar	2
,,	Muniyali	1		,,	Urali	2
,,	Gangol	2		,,	Siso	2
,,	Tilphara	7		,,	Sirwari	2
New Tehri	Chaura	2		,,	Trisula	2
,,	Nailchami	3				

In the affected areas of Nepal, about a dozen were reported as injured. No death was reported.

2.1.2. Number of house damages:

Houses of more than 1.80 lakh people of more than 2000 villages were affected by the intense shaking. The level of damage associated with a moderate size earthquake is usually much lesser as compared to the damage observed in the Chamoli earthquake. This may be due to the poor quality of construction materials and workmanship, effect of topography and the strong lateral heterogeneity in the affected area. In this earthquake, about 2200 houses collapsed and 1100 were destroyed. In addition 110,000 houses were moderate to heavily damaged. Most of the houses in the affected area, which suffered partial to complete collapse were made of stone walls and roof constructed of slates without any lintel bands. Besides the houses, the public utilities and facilities of all other kinds were also greatly damaged such as water pipe lines, electric and telephone lines etc.

Some houses collapsed and several sustained cracks in the affected areas in Nepal.

2.2. GEOLOGY AND TECTONIC SETTING

The Himalaya is one of the youngest orogenic belts of the world, resulted by continuous collision of Indian plate with Eurasian plate since early Eocene (Molnar and Tapponnier, 1975). The Himalayan arc extends geographically from Namche Barwa in the north-east (29 N, 95 E) to Nanga Parbat in the north-west (35 N, 75 E), over a distance of about 2500 km forming an arcuate structure convex towards south. The epicentral area of Chamoli earthquake lies in the Garhwal-Kumaun Himalaya (28-30.5 N, 79-82 E). The geology of the epicentral area is complex with many existing thrusts, faults, and folds (Figure 2.1).

The rock types in the Lesser Garhwal-Kumaun Himalaya are largely Precambrian sedimentary units. Geologically lesser Garhwal-Kumaun Himalaya is divided into northern and southern sedimentary zones due to significant lithologic variations. These sedimentary formations are tectonically overlain by several klippen structure consisting of largely amphibolite grade metasedimentary rocks and intrusive basement granite belonging to Precambrian Almora group. At some places, these klippen are underlain by lower klippen consisting of metasedimentary rocks of Precambrian Ramgarh group (Srivastava and Mitra, 1994).

In the Garhwal-Kumaun Himalaya region, three major tectonic units are separated from each other by Main Boundary Thrust (MBT) and Main Central Thrust (MCT). The outermost sub-Himalayas Tertiary belt is thrusted over by the Proterozoic-Eocene sequence of the lesser Himalayas along MBT. To the south of this, the steeply north dipping Main Frontal Thrust (MFT) separates this belt from the Indo-gangatic plains. Molnar [1986] has given models concerning the evolution of the Himalaya and the role of the MCT, MBT and MFT in the uplift of these mountains. Besides these major tectonic structures (MCT, MBT and MFT) there are numerous other geological structures, such as Vertical Nandaprayag fault trending NNW-SSE, Alaknanda fault trending E-W and northerly dipping MCT splays namely Bhatwari thrust (BT), Munsiari thrust (MT) and Vaikrita thrust. (Valdiya, 1980).

2.3. SEISMICITY AND SEISMOTECTONICS

The seismic activity in the Himalaya is ascribed to the northward movement of the Indian plate against the Tibet block of Eurasian plate (Molnar and Tapponnir, 1975). This movement is deforming the rocks and piling them to form the higher Himalaya and making area prone to seismic activity. The Kumaun Garhwal region lies in a so-called seismic gap between rupture zone of the 1905 Kangra earthquake and the 1934 Bihar-Nepal earthquake. The most of the seismic events in the Garhwal- Kumaun Himalaya region are located close to the MCT zone. The focal mechanism of most of the events show prominently thrust faulting. A violent earthquake of intensity ≥VIII occurred on Sep. 1, 1803 in this region (Smith, 1843). This earthquake was highly destructive and caused severe damage in Badrinath temple and upper portion of Qutab Minar. The micro-earthquake investigations carried out by the Department of Earth Sciences, University of Roorkee, Roorkee suggests that most of the stress released in the form of micro-earthquakes occur in the lesser Himalaya i.e. in the or south of the MCT zone

(Khattrei, et al., 1989). In the north of the MCT, the micro-earthquake activity is comparatively lesser, suggesting accumulation of stress in the south of the MCT.

Seeber and Armbruster (1981) have given models to explain the rupture in the different part of the Himalaya in terms of a great ‘detachment surface’ underlying the lower, higher and the Tethys Himalaya. Ni and Barazangi (1984) have given the seismotectonics of the Himalayan collision zone geometry of the under thrusting Indian plate beneath the Himalaya and Indo-gangatic plains. The steady state tectonic model of Seeber and Armbruster (1981) and also supported by Ni and

Table 2.4 Significant earthquakes in Kumaon Garhwal Himalayas (1947-94)

YEAR	LATITUDE	LONGITUDE	MAGNITUDE
1947	31.12	79.54	5.6
1949	31.12	79.54	5.8
1953	31.00	79.30	5.2
1958	30.00	79.54	6.8
1962	30.36	79.30	5.2
1962	30.30	79.18	5.4
1964	31.48	78.42	5.2
1968	30.30	79.06	5.1
1969	30.24	79.48	5.1
1969	30.30	79.24	5.4
1974	30.57	78.28	5.3
1974	30.36	78.30	5.2
1977	31.48	78.26	5.6
1977	30.30	79.30	5.3
1979	30.49	78.34	5.4
1981	31.47	78.28	5.2
1986	30.65	78.21	4.5
1986	31.05	78.00	5.6
1987	30.52	79.22	4.6
1987	30.36	79.12	4.9
1990	29.98	79.91	5.1
1990	30.35	79.16	4.8
1991	30.06	79.72	4.7
1991	30.61	79.29	4.5
1991	30.77	78.79	6.4

YEAR	LATITUDE	LONGITUDE	MAGNITUDE
1991	30.85	78.87	4.6
1991	30.69	78.73	4.8
1991	30.78	78.69	4.8
1992	30.70	78.85	4.7
1992	30.96	78.23	4.5
1992	30.78	78.76	4.7
1994	30.66	79.62	4.8

Barazangi (1984) suggest that MCT and MBT and other thrusts are all imbrications along a detachment surface and merge in depth with a low angle northerly dipping detachment surface.

The significant earthquakes in the Chamoli area between latitude 78°-80°E and longitude 29.5°-31.5° N in the last 50 years is listed in the Table 2.4. The magnitude of the earthquake ranges from 4.5 to 6.8. Table 2.4 shows that Garhwal-Kumaun Himalaya has experienced many moderate earthquakes in the last fifty years. The recent destructive earthquake in the area is Uttarkashi Earthquake of 1991 having magnitude 6.4. Most destructive Himalayan earthquakes in the last 150 years are Great Assam earthquake of 1897, 1905 Kangra earthquake, 1934 Bihar-Nepal earthquake and 1950 Assam earthquake.

2.4. STRONG GROUND MOTION

In view of high seismicity of the Himalayan region, the Department of Earthquake Engineering, University of Roorkee, Roorkee, has deployed several strong ground motions recording instruments in the region. The Chamoli earthquake was recorded at 11 accelerograph stations including one in the epicentral region (at Gopeshwar).

Table 2.5 Strong ground motion characteristics of Chamoli (1999) earthquake

No.	*Site*	Component	PGA (g)	EPA (g)	(10^{-2} gs)	P_D (10^{-3} gs^3)	f_c (*Hz*)
1.	DEQ Lat: 29.86 N Long: 77.89 E	N 55 W (L) N 35 E (T) Vertical	0.056 0.047 0.017	0.017 0.015 0.006	0.449 0.333 0.073	0.191 0.127 0.007	2.42 2.56 5.23
2.	**Tehri** Lat: 30.37 N Long: 78.50 E	N 63 W (L) N 27 E (T) Vertical	0.054 0.062 0.034	0.035 0.031 0.015	0.448 0.429 0.132	0.065 0.723 0.009	4.15 3.85 6.02
3.	**Gopeshwar** Lat: 30.40 N Long: 79.33 E	N 70 W (L) N 20 E (T) Vertical	0.199 0.359 0.156	0.117 0.291 0.049	2.952 8.151 2.548	1.322 2.645 1.603	2.36 2.77 6.3
4.	**Ukhimath** Lat: 30.50 N Long: 79.10 E	N 15 E (L) N 75 W (T) Vertical	0.091 0.096 0.047	0.039 0.046 0.025	0.824 0.837 0.198	0.061 0.415 0.099	5.79 7.1 7.06
5.	**Joshimath** Lat: 30.55 N Long: 79.57 E	N 80 E (L) N 10 W (T) Vertical	0.071 0.063 0.041	0.02 0.035 0.009	0.339 0.592 0.186	0.444 0.675 0.013	4.37 4.68 5.91

6.	**Chinyalisaur**	N 43 E (L)	0.052	0.03	0.365	0.062	3.84
	Lat: 30.55 N	N 47 W (T)	0.045	0.025	0.476	0.065	4.29
	Long: 78.33 E	Vertical	0.049	0.020	0.369	0.079	5.06
7.	**Ghansiali**	N 00 E (L)	0.073	0.031	1.124	0.094	5.45
	Lat: 30.42 N	N 90 E (T)	0.083	0.049	1.45	0.111	5.71
	Long: 78.65 E	Vertical	0.039	0.016	0.33	0.058	7.59
8.	**Uttarkashi**	N 72 E (L)	0.054	0.033	0.318	0.023	5.83
	Lat: 30.73 N	N 18 W (T)	0.064	0.034	0.499	0.032	6.23
	Long: 78.45 E	Vertical	0.023	0.009	0.073	0.016	3.39
9.	**Barkot**	N 10 E (L)	0.017	0.006	0.025	0.002	6.21
	Lat: 30.80 N	N 80 W (T)	0.023	0.015	0.052	0.003	6.22
	Long: 78.21 E	Vertical	0.019	0.009	0.028	0.001	7.69
10.	**Almora**	N 53 W (L)	0.027	0.013	0.117	0.016	4.21
	Lat: 29.58 N	N 37 E (T)	0.028	0.019	0.085	0.011	4.32
	Long: 79.65 E	Vertical	0.027	0.018	0.088	0.007	5.43
11.	**Lansdowne**	N 70 E (L)	0.005	0.002	0.003	0.00014	6.69
	Lat: 29.83 N	N 20 W (T)	0.006	0.002	0.004	0.00013	8.49
	Long: 78.70 E	Vertical	0.011	0.003	0.007	0.00030	7.75

Figure 2.2a shows the location of epicenter of the mainshock and the accelerograph stations where the event was recorded. Figure 2.2b shows the contours of peak ground acceleration (PGA) in the region. It may be noted that the ground acceleration attenuates very rapidly, which was also observed in Uttarkashi earthquake (Chandrasekaran and Das 1991). The rapid attenuation of ground vibration is primarily due to the presence of highly fissured rocks in the region.

Some parameters of engineering significance for the motions recorded at eleven stations are shown in Table 2.5. The characteristic frequency of these motions, as measured by the mean rate of zero upcrossing, shows considerable fluctuations indicating the influence of local geology and topography. In particular, the ground motion at Gopeshwar, situated near the valley, is unusually rich in low frequencies for the near field motions and energy is concentrated in a narrow band. On the other hand the ground motion recorded at Ukhimath, situated on the hilltop, is rich in high frequencies. Figure 2.3 shows the time history of recorded motion at Gopeshwar, the nearest station from the epicenter. It may be noted that although the high value of PGA (-0.359g) corresponds to a stray peak, its effective peak acceleration (EPA) is not much different from the recorded PGA. The EPA is defined as the peak value of the truncated ground acceleration record for which the spectrum intensity is 90% of that computed for the original time history (Watabe & Tohdo 1979). Moreover, its energy is concentrated in the period range (0.1-2.5 s) used in the computation of spectrum intensity as shown in the spectral acceleration plots for 5% damping (Figure 2.3). The earthquake destructiveness potential factor P_D is commonly used for comparing the severity of ground shaking which simultaneously accounts for the effect of maximum amplitude, duration and frequency content of strong ground motion and is defined as where I_A is Arias intensity and is the mean rate of zero-crossing (Araya & Saragoni 1984). The effect of rapid attenuation of strong ground motion is also reflected in values of P_D as shown in Table 2.5.

2.5. CONCLUSIONS

The loss of human lives due to this earthquake was much less as compared to the Later earthquake (1993), although quality and damage to the houses was more or less same. This may be due to the thinner population density in the affected area. The maximum intensity assigned to this earthquake is VIII- on the MSK scale. The maximum damage was concentrated near the apex of the major axis of the elliptical zone 50x20 km elongated in WSW-ENE direction. The damage to the houses was much more than the expectation due to the poor quality of construction material used (e.g. the dominating stone houses in mud mortar without any lintel band with heavy slate roof). Analysis of strong ground motion records from eleven stations indicate that the ground motion attenuated very rapidly which can be attributed to the presence of highly fissured rocks. This observation is consistent with the observed intensity of shaking. Also ground motions in the epicentral region are relatively rich in low frequencies indicating a deep focus event.

CHAPTER 3. MACROSEISMIC SURVEY AND SITE EFFECTS

3.1. INTENSITY ASSESSMENT

A detail survey of the damage caused by the Chamoli earthquake of March 29, 1999 was carried out by a joint team of Department of Earthquake Engineering, University of Roorkee, India and National Society for Earthquake Technology (NSET-Nepal), Nepal for intensity mapping, preparation of the isoseismal map and study of the local site effects. The affected areas were identified by scanning the local and the national News Papers and also the information regarding damage provided by the residents of the area. The terrain changes and the severe damage to the structures were mostly confined between the Alaknanda and Mandakini river valleys, namely: Ukhimath, Jakholi and Pokhari blocks of the Rudraprayag district and Devaldhar, Mandal, Tilphara Tehsils and Chamoli as well as Pipalkoti towns of the Chamoli district. The ground deformation include landslides, rock and boulder dislodgment, ground fissures, slope failure and the changes in the spring discharge. The walls of the most of the houses of the affected area were constructed of stone and mud mortar and roofs were made of heavy stones. In the entire area, it was observed that those houses whose walls were made of thin and small pieces of slates suffered much less damage as compared to the houses whose walls were made of the large stone blocks of uneven shape.

The intensity to a particular locality was assigned on the basis of information collected by interview of the resident and the visual inspections. MSK (Medvedev-Sponheuer-Karnik-1964) and ESS (European Society of Seismology-1992) intensity scales were followed to assign the intensity value in the different localities. The intensity was assigned to a specific locality keeping in view the type of structure (e.g., A-poor quality such as stones/bricks and mud mortar, B-good/moderate quality such as bricks and cement mortar or C-good quality such as reinforced concrete or steel), the grade of damage to each structure (e.g., Grade I to Grade V; see annexure 1 for description of damage Grades) and the number of structures suffered to a specific grade of damage (e.g., single/few, many or most). The methods adopted to assign intensity are always subjective based on the judgment and it is difficult to apply a uniform criteria. Therefore, while assigning intensity to a locality the team carefully noted the marked difference in the damage to the buildings, type of materials used for construction, their pre-earthquake condition and its areal extent. The spatial distribution of earthquake intensity in the Chamoli and adjoining regions is described along the following tracts.

3.1.1. Tract I: Devoprayag-Kanjal-Srinagar-Rudraprayag

In Devoprayag city minor cracks in both the A and B type houses were observed and people reported partial awakening and frightening to some extent. The river Ganga starts from this place, the merging of Bhagirathi and Alaknanda rivers. A landslide was observed at the bank of Alaknanda river near Kanjal village, on the Devoprayag-Rudraprayag road. This slip occurred in a collovial formation having a steep slope towards the river (Figure 3.1). The intensity to these localities was assigned V^{+} on the MSK scale.

Similarly, intensity V^+-VI was assigned to Srinagar and Rudraprayag towns. The A and B type houses at these places suffered a damage of grade G1 and grade G2 and in some cases it was of grade G3. Moderate damage occurred to the houses in the Srinagar town, especially to the poor stone houses-plaster partitions cracked, fall of plaster and tiles etc. The lesser damage to Srinagar town may be attributed to flat and hard ground and very small elevation difference between the ground and the base of the Alaknanda river. In Rudraprayag, intensity V^+ was assigned at the base and intensity VI^+ was assigned at the top of the valley type topography of the town. This intensity variation may be due to the topographic effect. Also, more damage was observed in the first floor as compared to the ground floor. Mandakini river merges into the Alaknanda river in the Rudraprayag city. Hair to minor cracks were observed in most of the houses and minor cracks were observed even in a newly built building. An old school building suffered minor damage. Villagers reported that the houses built on the higher elevation have suffered more damage upto partial collapse as compared to the houses near the base of the hill. Most of the houses, built of stone wall and slate roofs suffered more damage as compared to houses whose roofs were made of rod-brick-concrete. In this village, team members educated the villagers, how to make houses using stone, so that it can withstand during the quake.

3.1.2. Tract II: Tilwara-Agastmuni-Chandrapuri-Guptkashi

Intensity VI^+ was assigned to Tilwara-Agastmuni and the adjoining region. Two landslides; on the both front banks of the river Mandakini were observed (Figure 3.2). The right-side slip was in the collovial formation of the river (>70º dip) and left-side slip was on a rock mass. Minor cracks in the walls (near the opening of the windows and doors) of buildings of the Government Inter College (GIC), Agastmuni were observed. Horizontal displacement of the first floor of a building of the same GIC was also observed. This College is situated on the left bank of the Mandakini River at 10-15m height. Minors to fine cracks were observed in some B and C type houses. The buildings of the GIC suffered more damage as compared to the other nearby buildings. The earthquake was felt by all and many were frightened. Villagers reported the swinging of the hanging objects, falling of unstable things and shifting of the light furniture etc.

The intensity of shaking in Bhatwari-Sonar village was of order of VII-VII^+ from base to top of a hill (20-35m) on which this village is situated. Two casualties were reported in this village due to the earthquake damage. Many A type houses were partially and few were collapsed. A two storey building in the village suffered grade G3 damage in the ground floor and only grade G1 damage in the first floor. The cause of this dissimilarity in the damage may be due to the poor quality of ground floor (stone and mud mortar) and good quality of the first floor (brick and cement mortar). Two houses which were built on a large rock boulder were unaffected by the quake. Longitudinal cracks in the sloping ground were observed at many places. Most of the villagers were sleeping out door in the tents or below the trees or open sky. General panic, awakening and the sound of the mixed passing train and the thundering was reported. Villagers also reported that they were unable to distinguish their sound due to falling and crushing of the objects. The hill on which, this village is situated is composed of rounded pebbles/boulders and soil and is surrounded by two sides by a hard quartzite rocks (Figure 3.3). This hill seems to be very younger than the surrounding formations. The damage to this village may be attributed to the strong lateral discontinuity and soft formation. The increase of damage with height may be attributed to the topographical effect. Intensity $VIII^-$ was assigned in Dobalko village, which is situated on the same hill but at higher elevation (10-20m) just above the Bhatwari-Sonar village. In this village, out of eight houses, two were collapsed, three were partially collapsed and the rest suffered major damage.

Damage in the nearby Chandrapuri village on the front right bank of the Mandakini river was very less as compared to the Bhatawari-Sonar and Dobalko villages. Lesser damage in this village may be attributed to the gentle slope of the ground and only 2-5m elevation from the base of the river. Most of the houses in this village were of A and B type and suffered damage of grade G1 and grade G2. Some old stone houses suffered damage of grade G3 and G4 also in the inner side but were looking safe from the outside. Shifting and overturning of light objects and swinging of hanging objects were reported by the villagers. Intensity to this village was assigned as VI^+ on the MSK scale.

Ten villages between Kyunja and Kansili villages under Agastmuni Tehsil were cut off from the rest of the World for five days due to the heavy landslides. Intensity VII^+ was assigned to Kandara and Kyunja villages. A large landslide was observed just before the Kandara village (Figure 3.4). Three deaths were reported in the Kyunja village. Housing and Urban Development Corporation (HUDCO) has adopted Kyunja village to develop as a model village, so that local carpenters and the masons can be trained to construct earthquake resistant houses (Indian Express, April 5, 1999). The earthquake and its aftershocks triggered a series of landslides and sent huge boulders rolling, which blocked roads, hampering relief and rescue operations in this area.

In the Kansili village, most of the 100 houses were either partially collapsed or were destroyed and rest were unsafe for living. General panic and awakening was reported. A villager reported that he was unable to run in his room. This village is situated on the right bank of the Kyuja Gad river on the steeply dipping ground. Figure 3.5 depicts partially collapsed stone houses of the Kansili village. The intense damage in this village may be due to the steep topography and poor quality of the houses, basically stone houses with mud mortar. One casualty was reported in this village. The intensity to this village was assigned as $VIII^-$. The intensity VII was assigned to the nearby Pingala Pani and Unali villages. These villages are situated at the base of the valley of the Kyuja Gad river on almost flat topography. Lesser damage in these villages may be due to the deamplification of the ground motion. Three casualties were reported in Pingala Pani village. A large number of land/rock slides were observed in this area. Intensity VI^+ was assigned in the Guptkashi town and the adjoining area. Many A type houses in this area suffered a damage of grade G2 and few of grade G3 and some B type houses suffered damage of grade G1 and G2. Residents of this locality reported general awakening and frightening to some extent.

3.1.3. Tract III: Ukhimath-Chopta-Mandal

Although, the damage in the Ukhimath town was very less but the casualty reported in different villages of this block is 22 (Table 2.3). Intensity VI^+ was assigned in the Ukhimath town area. Slight damage to the town may be attributed to the hard crystalline rock and absence of the soil cover. Five casualties were reported in the Makku village, which is 16 km off the Ukhimath-Gopeshwar road. This village is the most damaged village of the Ukhimath block of Rudraprayag district, where most of the houses were destroyed. Villagers were residing in the tents or in open sky. It was reported that four A type houses were collapsed and rest were severely damaged and leaving 400 people homeless. On the basis of above information it seems that the intensity of shaking in this village was of the order of VIII- on the MSK scale. A villager reported similar type of damage in Charkhurh village, but lesser intensity than Makku village. The Charkhurh village is situated in between Makku and Chopta village. The Ukhimath-Gopeshwar road was blocked for some days due to the heavy landslides between Gopeshwar and Mandal.

Intensity VI was assigned to the Chopta village. In this village grade of damage to A type houses were only G1 & G2. Chopta village is situated at 2700m elevation on the almost flat topography of the Chopta hill (Figures 3.6 and 3.7). The less damage to this village may be attributed to flat topography and the hard rock area. The roof of the Tungnath temple developed huge gap and a nearby Ashram was severely damaged during this earthquake. The temple is considered as fifth Math of Hindus like Badrinath, Kedarnath, Gangotri and Ymunotri. It is situated at a distance of about 3km from the Chopta village. This hundreds years old temple was first damaged in the 1860 tremor and secondly in this Chamoli earthquake. The intensity to this locality may be assigned as VI^+. The frequency of landslides from Ukhimath to Mandal was less as compared to Mandal to Gopeshwar, in Agastmuni and the Devaldhar Tehsils.

Intensity VII^+ -$VIII^-$ was assigned from base to top of the Mandal valley, situated on both the bank of the Balkhila river. Residents of this valley reported that they were unable to run during the quake and heard a mixed sounding of a passing train and thundering. The villages like, Khalla, Gondi and Mandal proper, situated on the almost flat ground at the base of the valley suffered lesser damage as compared to the villages, Siroli and Makroli, which are situated at higher elevation in the same valley. Intensity $VIII^-$ was assigned to Siroli and Makroli villages. These villages are situated on a hill having some soil cover with a steep slope (more than 45^o). Intensity VII^+ was assigned to Mandal, Khala and Gondi villages of the Mandal valley. The longitudinal cracks along the road and in the sloping ground were observed. In this valley soil thickness is of the order of 2-5 feets only. A Hostel of Sanskrit Degree College, Mandal and the nearby State Allopathic Dispensary were partially collapsed. The reason for the severe damage to these structures is their stone walls made of large boulders in mud mortar. Most of the stone houses suffered moderate damage and few suffered severe damage in the Mandal proper village. In this village it was observed that the houses whose wall were made of thin slate or even large stone boulders with thin slate suffered much lesser damage as compared to the houses whose walls were made of only large stone boulders.

In Vairagna and Badakoti intensity VII^+ was assigned. Three casualties were reported in the Badakoti village. An old building of a school in the Vairagna village collapsed and other suffered a damage of grade G2 during this earthquake. Cracks in the sloping ground were observed in the longitudinal direction to the Balkhila River. Residents of this village reported that a spring started discharging, although this occurs in the rainy season, but it was decreasing continuously with time. Another spring in this village stopped discharging, in which water was flowing before earthquake. All the residents were awakened and many were frightened.

Gwan, Dewaldhar, Pawaldhar, Markand, Sirokhoma and Mawan villages are in the Dewaldhar Tehsil. These villages are situated on a ridge type formation between Vir Ganga and the Balkhila river (Figure 3.8). Although the worst damage was typically to older stone buildings, minor damage was common in newer ones. In spite of much costly damage in places like Mawan village, at many places damage was slight like in the nearby Sirokhoma village. The intense damage in the Dewaldhar Tehsil may be attributed to the collovial ridge type formation between the two river valleys. The intensity to this area is assigned VII$^+$ -VIII- on the MSK scale. In Dewaldhar village, cracks in and along the road were observed on the steep slope and intensity VII$^+$ was assigned. In this village, it was reported that the discharge of a spring was increased but it ceased to zero after about 20 days. In Pawaldhar village, more damage was observed as compared to the Dewaldhar. This village is on a steep sloping ground just below the Dewaldhar. In this village some houses were collapsed and rest were severely damaged. Two and one casualties were reported in the Dewaldhar and Pawaldhar villages respectively. A ground fissure of about 6" width and 40-50m length in the NE-SE direction along the base of a hill was reported by the residents in the nearby village. This village is about 50m above the Dewaldhar village.

Mawan, the most damaged village of the Dewaldhar Tehsil is situated on the mouth of the ridge facing towards the junction of Vir Ganga and the Balkhila rivers. Out of the three B type houses, one was collapsed and two were partially collapsed in this village. Intensity VIII- was assigned to this village. The intense shaking may be due to the ridge effect, steep slope from the front side and the collovial formation. The lithology of the ridge mass is not homogeneous. A lot of soil and rockslides were observed in and around the Dewaldhar Tehsil. Cracks in the ridge on slope in the EW direction were observed due to slope failure and the ridge amplification (Figure 3.9). Very less damage was observed in the nearby (100m) Sirokhoma village. A primary school of Sirokhoma suffered a damage of grade G2 only (Figure 3.10) and intensity to this locality may be assigned as VII only. Damage in this village is very less since it is situated on the gentle slope and on one side of the ridge and not on the crest. Whereas, Mawan village is situated on the steepest crest of the Dewaldhar ridge. The damage to the houses on hard rock on the left bank of the river Vir Ganga were very less as compared to the damage in the Dewaldhar Tehsil. The sliding of very large boulders from the high elevation caused heavy damage to a house and a nearby steel bridge in the Sirokhoma village.

3.1.4. Tract IV: Gopeshwar-Pipalkoti-Joshimath-Badrinath

Intensity VII was assigned in the Ghighran village, situated about 7.0 km away from the Gopeshwar town. The village ground has gentle slope (10-15) and soil thickness of 10-15 feet. A two storey building suffered minor damage in the first floor and major damage in the ground floor in this village. The ground floor of this building was made of stone and mud mortar whereas the first floor was made of bricks and cement with a lintel band. In this village, it was noticed that houses with lintel band suffered very less damage as compared with the same type of houses without lintel band. The school building of Government Inter College of this village, built on a flat ground suffered a damage of grade G1 only. No cracks were observed in the nearby swampy ground. A crack in the hill was reported and a number of landslides were observed in the nearby hill.

Damage in the main Pipalkoti city was very less (of the order of intensity VI$^+$ only) since it is situated on flat and hard ground. Whereas, the Pipalkoti village (Chauk bazar) situated on a sloping ridge type formation with a soil thickness of about 4-5m suffered heavy damage. Figure 3.11 depicts the ridge type formation between Alaknanda river and a deep Nala. Two casualties were reported in this village, one in the main shock and other due to next day aftershock. In Chauk bazar most of the buildings were severely damaged and few were partially collapsed. A two storey building which was looking safe from out side but was severely damaged in the inner portion, particularly partitioning walls. The Badrinath and Kedarnath community rest house in Pipalkoti was badly damaged. Intensity to the localized Chauk Bazar was assigned as VII^{+}. The higher damage in Chauk bazar may be attributed to slope, soil cover and the ridge type formation.

Intensity VI^{+} was found in both the Talli and Malli of the Tangni village. Most of the A and B type houses suffered damage of grade G1 & G2. Soil thickness and slope of the ground was 7-10 feet and 30-40° respectively. Longitudinal cracks in the terrace like land were observed. Similarly, minor to fine cracks were observed in most of the B and C type buildings of the Helong town. Residents of this town reported that they were unable to run during the earthquake. It was also reported that out of the 100 building four collapsed and three were partially collapsed. Intensity VII was assigned to Helong town.

Intensity VII^{+} was assigned to the Bhargi and Urgam village on the basis of the information provided by the residents of these villages, regarding damage and the landslides. These villages are situated at 7-10 km away from the Helong town. In Bhargi village a rockslide was reported towards the south, which is situated on a steep slope. In the Urgam village damage was more as compared to Bhargi village due to more soil thickness (15-20 feet). In this village damage to houses were more which were on the sloping ground and at the higher elevation as compared to the houses on the ground having flat topography with lower elevation. Loose soil slip towards the north was reported in the Urgam village.

Intensity VI - VI^{+} was assigned in Joshimath and Pandukeshwar cities. Two rockslides were observed just after Joshimath on the Joshimath-Badrinath road (Figure 3.12). Joshimath temple suffered no damage and only minor and fine cracks were observed in the A and B type buildings of the town. No damage was observed in the famous Badrinath shrine built at the right bank of the Alaknanda river at a height of 3410m from the mean sea level. Only fine cracks were observed in some A type houses. Intensity V was assigned to this locality.

3.1.5. Tract V: Chamoli-Sonala-Trisula-Shem:

The Chamoli town along the main road was least damaged as compared to lower and upper Chamoli. This low damage may be due to the hard rock, flat ground and better quality of buildings. Chamoli town is situated on the left bank of the Alaknanda river. The intense damage in the lower Chamoli was localized in a small area. In this localized region most of the houses were either collapsed or were severely damaged. This may be due to the effect of steep slope, soil with rounded pebbles in that area. Houses built on gentle slope near the base of the river and on hard rock suffered much less damage. Similarly, lesser damage was observed to the houses, which were built on hard rock on the right bank of the river. In upper Chamoli, the intense damage was confined just after the steep slope. At this small confined region most of the houses were destroyed. The buildings suffered lesser damage, which are situated at some distance from the slope change on the gentle sloping ground. A jail in upper Chamoli was partially collapsed and six prisoners were killed. Intensity VIII- was assigned to the Chamoli town although intensity of shaking was of the order of VIII in some localized region of the city. The casualty reported in this town is 26 (10 in upper and 16 in lower Chamoli).

In the Sonala village, on the Chamoli-Pokhari route, most of the A and B type houses suffered a damage of grade G1 and grade G2 and a few suffered damage of grade G3. Intensity in this village was VI^{+}. Intense damage was observed in a village situated on a ridge type structure near Kathura village on the same road. Intensity VII was assigned to this village, situated on the ridge. Similarly, intensity VI^+ was assigned to Chhemi and Trisula villages on the same route. A rockslide was observed in Trisula village. Casualty reported in Trisula village was 2. Most of the houses of this village suffered minor damage and few were severely damaged.

In Shem and Sikari villages, few A and B type buildings suffered damage of grade G3 and grade G4 and rest of the buildings suffered minor damage. These villages are situated on the left bank of the Nigol river. In the base of the river damage to the houses was lesser as compared to the houses built on some elevation. The effect of slope variation was also observed in the Shem village since a newly built B type house was severely damage near the slope change whereas the houses which were at some distance from the slope variation suffered much less damage. This two storey newly built house with brick and cement mortar suffered damage of grade G3 in the ground floor with a rotational component in the displacement and only grade G1 damage in the first floor. This may be due to the only half built portion of the first floor. The doors of the nearby house were rendered inoperative due to the crushing. It was reported that every resident was awakened and frightened and were unable to run due to strong shaking. Intensity VII^+ was assigned to this locality on the MSK scale.

3.1.6. Tract VI: Maithana-Tilphara-Nandprayag-Karnprayag

Intensity VII^+ was assigned to the Maithana and Tilphara villages. Many buildings of these villages suffered severe damage and some were partially collapsed. Seven children died in Tilphara village due to fall of debris on them since they were unable to run out of their houses with their parents. The residents of these towns reported general awakening and frightening. The falling and sliding and overturning of the domestic objects were reported. Most of the residents stopped residing in their houses due to fear and were seen residing out side in the tents or below the trees. The intensity of damage was similar in the Nandprayag, Karnprayag and Gaicher cities. Sudden increase of flow of water in a thin stream was reported in Purana Bazar of Nandaprayag city. This may be due to the widening of the existing under ground fissures. In both the cities, A and B type houses suffered damage of grade G1 and grade G2. The residents of the these cities reported general awakening, frightening and failure of power supply. Intensity VI^+ was assigned to these cities.

3.2. ISOSEISMAL MAP

The extensive damage survey was done by the team members between the river valleys of Alaknanda and Mandakini rivers along the existing motorable roads. The damage survey was done from Chamoli to Badrinath (71km) in the NNE direction, from Chamoli to Srinagar (100km) in the SSW direction along Alaknanda valley, from Chamoli to Ukhimath (42km) in NNW direction, from Rudraprayag to Guptkashi (45km) along the Mandakini valley and the areas which lies in between these two river valleys. An isoseismal map has been prepared based on intensity assigned at different localities by visual inspections and the interviews of the residents. The preparation of the isoseismal map has own importance since it provides the information regarding the nature of the earthquake rupture, approximate focal depth, epicenter and the macro-seismic effects in the affected region.

Figure 3.13 illustrates the isoseismal map for the Chamoli earthquake of March 29, 1999 showing isoseismals of intensity VI and VII as well as the local intensity values. The maximum intensity $VIII^-$ was observed in two regions namely; Devaldhar and Mandal valleys and the Chamoli town in NE direction and Kyunja tehsil and Dobalco village of Chandrapuri Tehsil in the SW from the epicentre (Based on the isoseismal map). Intensity $VIII^-$ was assigned to Chamoli, Mawan, Siroli, Makroli, Makku, Kansili and Dobalko villages/towns. The residents of these localities reported general panic, awakening and mixed sound of the passing train, thundering and the airplane. In these localities large number of ground fissures and landslides were observed/reported. Most of the houses of these villages/towns were either razed to ground or were partially collapsed and remaining were unsafe for living. Sliding and overturning of light to heavy furniture, falling of the objects and the violent swinging of the hanging objects were reported.

The intensity VII^+ was assigned to Bhatawari-Sonar, Kyunja, Akhori, Kandara, Khalla, Gondi, Vairagna, Badakoti, Pawaldhar, Bhargi, Urgam, Gopeshwar, Maithana and Tilphara villages/towns. The degree of damage and frequency of the landslides and the ground fissures was lower as compared to the places where intensity $VIII^-$ was assigned. Intensity VII was assigned to Mandal village, Sirokhoma, Dewaldhar, Markand, Gwan, Pingala Pani, Unali, Gighran, Pipalkoti,and Sem-Sikari villages/towns. The residents of these localities reported general awakening and frightening of many people and mixed sound of passing train and thundering. In these villages/towns, a lot of ground fissures and landslides were also observed but of lesser frequency. Many poor houses of these localities suffered heavy damage and some good quality houses suffered moderate to minor damage. Sliding and overturning of light furniture, falling of objects and swinging of the hanging objects were also reported. An isoseismal line for intensity VII was drawn using the intensity of localities having intensity (VII. The length of major and minor axes of the elliptical isoseismal line of intensity VII, oriented in WSW-ENE are about 50km and 20 km respectively.

Similarly, isoseismal line for intensity VI was drawn using the intensity value of VI^+ of Chandrapuri village, Guptkashi, Ukhimath, Tungnath, Tangni, Joshimath, Sonala, Kathura, Chhemi, Trisula, Nandprayag and Karnprayag localities, intensity VI of Srinagar, Rudraprayag, Tilwara, Agastmuni, Chopta and Pandukeshwar localities and intensity V-V^+ of Deoprayag, Kanjal and Badrinath of the surveyed area. The residents of these localities reported general awakening and frightening to some extent and sound of a passing train or heavy truck. Few landslides and ground fissures were observed in these localities. The shape of the isoseismal VI is also elliptical but it has been rotated anti-clockwise. This rotation of the isoseismal VI may be due to the presence of Alaknanda valley. The closer isoseismal lines in the ENE direction indicates rapid decrease of intensity and widely separated in the WSW direction indicates slow rate of decrease of intensity. This may be due the harder crystalline rocks in the higher Himalaya and the comparatively softer rocks in the lower Himalaya.

Systematic intensity mapping of this earthquake was not carried out in Nepal. In the areas visited by the team, the maximum intensity was IV- V MMI.

3.3. LOCAL SITE EFFECTS

The changes observed in earthquake intensity from one location to another are the results of several factors such as source mechanism, the epicentral distance, geological characteristics of the rocks through wave has propagated, wave interference and the local site conditions. Out of these, the local site conditions play a major role in amplitude amplification, increase in signal duration and modification in the frequency content in the wave front and finally the damage pattern. The effect of local site condition includes the effect of soil and its thickness, surface topography and the lateral discontinuities. The historical reference regarding earthquake damage due to local site condition, extents back nearly 200 years. Wood (1908) and Reid (1910) showed that the intensity of ground shaking in the San Francisco earthquake (1906) was related to local soil and geological conditions. Mac Murdo (1924) noted that the buildings situated on the rock were not much affected as those situated on the soil cover in the case of Catch earthquake (1819) of India. Gutenberg (1927) developed site dependent amplification factors from recordings of micro-earthquakes at sites with different subsurface geological conditions. In recent years, strong motion instruments have allowed local site effects to be measured quantitatively. Recent examples regarding the effects of local site conditions includes Michoacan (1985) earthquake which caused only moderate damage in the vicinity of its epicenter but caused intense damage some 400km away in the Maxico city (Dobry and Vacetic, 1987), damage caused by the Loma Prieta, California earthquake (1989) in the city of San Francisco and Okland (U.S. Geological Survey Staff, 1990) and damage caused by Jabalpur earthquake (1997) of India (Rai et al., 1997).

3.3.1. Soil and Lateral discontinuity effects:

It is well known that lower shear strength in the soil/ surficial layer facilitates the amplitude amplification due to continuity of energy flux, mode conversion and increase in signal duration (Vidale and Helmberger, 1988 and Narayan, 1998). Further, it has been observed that duration of signal increases with the increase of soil thickness and amplification factor increases enormously whenever there is resonance between wave period and the soil period (Narayan, 1998).

The best example of damage caused by lateral discontinuity was observed in the Bhatwari-sonar village. This village is situated on the sloping hill at the left bank of river Mandakini on the Rudraprayag-Ukhimath road. At the same time, damage in the nearby Chandrapuri village was much lesser. The hill mass is composed of rounded pebbles and young soils (Figure, 3.3) and is surrounded by the hard quartzite rocks. The thickness of soil on this hill was 4-6 feet. An Amplitude amplification and local surface wave generation in the softer medium and large differential motion caused by shorter wavelength of the surface wave may be the reason behind the observed damage. The mixed effects of loose formation and lateral discontinuity on the damage was also observed at the localities like Pipalkoti (Chauk Bazar), lower Chamoli and Kanjal village. In the past, a large number of field observations have also been reported significant increase of damage in the narrow zone located along strong lateral discontinuities (Moczo and Bard, 1993).

3.3.2. Effect of the surface topography:

It has been reported based on field observations and instrumental evidences that surface topography considerable affects the amplitude and frequency content of the ground motion (Celebi, 1987 Geli et al., 1988 and Faccioli, 1991). Theoretically, the amplification of seismic wave at the ridge crest and convex topography and deamplification over concave topography have been predicted to some extent (Sanchez- Sesma, 1990, Sanchez-Sesma and Campillo, 1993). The amplification near the crest of the ridge was measured in five earthquakes in

Matsuzaki, Japan, the average peak crest acceleration was about 2.5 times the average base acceleration (Jibson, 1987). The effects of topography like ridge, valley and slope variation are described below.

Effect of ridge:

The effect of ridge on the damage was observed in Mawan, Devaldhar, Pawaldhar and the nearby villages situated on Dewaldhar ridge between Vir Ganga and Balkhilla rivers (Figure 3.8) and in Melauli in Nepal. The damage in the Mawan, Devaldhar, Pawaldhar villages, situated on the crest of the ridge was much more than the other villages Sirokhoma, Markand and Gwan, situated on the gentle slope of the ridge. Further, damage in the Mawan villages was much more than Dewaldhar and Pawaldhar villages due to steeper crest having steep slope towards the junction of the rivers, Vir Ganga and Balkhila. Similarly, the damage to Pipalkoti (Chauk Bazar) may be attributed to some extent to a ridge type formation between Alaknanda river and a deep Nala. Effects of ridge was also observed in a village near Kathura village.

Effect of valley:

It has been predicted numerically that in the valley, there is deamplification of the amplitude due to the defocusing effect. The intensity in a valley may be 1-2 scales lesser as compared with the surrounding, if it is free from the soil deposits. This type of effect was observed in the Mandal valley and Pingala Pani, Unali and Chandrapuri villages. The Mandal valley is on the Balkhila river. The damage in the Mandal proper village and the Khalla village was lesser as compared to the other villages of the Mandal valley, since these villages are situated at the base of the valley. The houses of the other villages (Siroli, Makroli and Gondi), which were situated at some elevation suffered much more damage. Similar type of effect was observed in the valley of Kyuja Gad river. The damage to the houses in the Pingala Pani and Unali villages was lesser as compared to the Kansili village, since former two villages are situated at the base of the valley and the Kansili village is situated on the steeply dipping part of the valley. Similarly, the damage in the Chandrapuri village situated on almost flat ground at the right bank of the Mandakini river suffered lesser damage as compared to the nearby Bhatawari-Sonar village, which was situated on the left bank of the river at some (25-50m) elevation.

Slope effect:

Complicated damage pattern was observed on the hills with variable slopes. The houses situated on or near the bank of a steeply sloping hill suffered much more damage as compared to the houses, which were at some distance from the steep portion or on the gentle sloping part of the same hill. The damage pattern was following the amplification factor according to the French recommendation; AFPS-92, on the slope variation. Damage observed in lower and upper Chamoli, Augustmuni village and Shem-Sikari villages can be attributed to the effect of slope variation. The intense damage at the higher elevation of lower Chamoli and just after the steep slope in the upper Chamoli is to some extent in accordance with the French Recommendation-AFPS 92 (Figure 3.14).

3.4. GROUND DEFORMATIONS

3.4.1. Spring

The earthquake has also affected a number of natural springs of the meizoseismal area. While in some places underground streams have suddenly gone dry and at other places the underground streams have opened up with water gushing out. It was also reported that some springs have changed their direction. The sudden increase of flow of water in a thin stream near Purana Bazar was reported after the earthquake (Hindustan Times; April 7, 1999). This may be due to the widening of the underground fissure. A serious water crisis was developed in the Gopeshwar city since springs related to water were blocked due to the quake at many places. But in the nearby village of the Gopeshwar town, the increase of water in a spring was reported (Dainik Jagaran; April 1, 1999). Similarly, the residents of Vairagna village reported that a spring started discharging, although this occurs in the rainy season, but discharge is decreasing continuously with time. Another spring in this village stopped discharging, in which water was flowing before earthquake. According to The Hindustan Times dated March 31, 1999 'In Rudraprayag district, water sources had run dry at some places as a result of the havoc caused by earthquake'. Change in ground water table was reported in Ghigharan village after the earthquake.

3.4.2. Fissures

The ground fissures observed in Chamoli and Rudraprayag districts due to the recent Chamoli earthquake were surficial in nature and were caused by differential movement in the surface layer and were not associated with the earthquake rupturing process. Even, the direction of ground fissures were not associated with the direction of wave propagation and were purely governed by the local site conditions. Most of the ground fissures were observed near to the epicentral area within the intensity zone of VII. Most of the fissures are associated with road embankments, collovial/loose soil formation or strong lateral heterogeneity and on some terraced slope on the hills. The fissures were of 20-30 m length and 2-3 cm width. A ground fissure, about 100m long was observed along the road embankments in Mandal village. It was impossible to measure the actual dimension of the ground fissures since team visited the site after about one month. The cracks along the junction of the base of the rock mass and the soil deposits was reported by villagers of the Pawaldhar village. The crack may be due to the settlement of the alluvium formation or due to the differential ground motion. In Mawan village, cracks were observed in the sloping ground. These cracks were due to the colluvium formation and low shear strength.

3.4.3. Landslides

Many type of landslides were observed during the damage survey such as rock fall, landslides, sliding along joints, slump and debris flows. The frequency and the type of landslides were controlled by geology. For example, landslide activity was small in limestone dominated areas and landslides, slumps and debris flow were numerous in sandstone and mudstone dominated areas. New landslides were triggered and old landslides were reactivated in this earthquake. Most of the landslides are within the intensity zone of VII. Many rockslides are observed in the epicentral area along the road from Mandal to Gopeshwar. The rock type in this area is quartzite and schist. Debris slides were observed along the road between Joshimath and Chamoli. The major rock type in this area is phyllite and calcareous rock. The biggest landslide reactivated in this earthquake was in the Ghigharana village. The slide was circular plane failure type. Along the failure surface big holes about 1–2 m. in diameter were observed. The rock type around Ghigharana slide area is amphibolite.

3.5. CONCLUSIONS

The Chamoli earthquake of March 29, 1999 did not show any evidence of surface faulting. Even the direction of ground fissures and landslides have no co-relation with the direction of strike of the rupture and these activities were mainly governed by the local favourable conditions. The earthquake damage survey depicts that effects of topography and strong lateral heterogeneity have played major role in the damage.

The elongation of isoseismal line of intensity VII in WSW-ENE direction depicts that the strike of the slip may be in WSW-ENE direction. Since higher isoseismal lines are generally believed to be elongated along the strike of the fault. This conclusion was drawn by Kaila and Sarkar (1978) on the basis of analysis of orientation of the isoseismal lines of the 26 major Indian earthquakes and the strike of the causative faults. For example, higher isoseismals of Kangra earthquake (1905), Bihar-Nepal earthquake (1934), Assam earthquake (1950) and the recent Uttarkashi earthquake (1991) were elongated in NW-SE, E-W, NE-SW and NW-SE directions respectively. It seems that the epicenter of this earthquake lies on one of the MCT splays between Alaknanda and the Mandakini valleys. It is concluded on the basis of above discussions, damage pattern and the orientation of the isoseismal lines.

The elongation and anti-clockwise rotation of the isoseismal line for intensity VI may be due to the effect of the Alaknanda river valley in the almost NE-SW direction. The elongation of isoseismal lines along the river valleys were also observed in the case of Assam earthquake (1950), Calcutta earthquake (1964), Bihar-Nepal earthquake (1934) and the Baluchistan earthquake (1909). This effect is generally observed on the isoseismal lines of lower intensity. Whereas, the shape of isoseismals line for higher intensity is governed by the rupturing process.

The pattern of damage i.e. maximum damage in the strike direction, at some distance from the epicenter (/based on the observation) and not at or near the epicenter depicts that the slip has been on a low angle fault. This type of result has also been obtained by Narayan (1998) based on the numerical radiation pattern and the simulation of various type of slip motion. So, it can be inferred on the basis of damage pattern and shape of the isoseismal line that this earthquake occurred on a low angle-dipping plane having strike in the WSW-ENE direction. The empirical relation I_0=1.5M-4.5Log h +4.5 suggest a focal depth of 25 km for this earthquake. This focal depth based on the empirical relation seems to be correct since Khattri et al. (1989) and Ni and Bazarangi(1984) have reported depth of the detachment surface in the Garhwal-Himalaya region 18-22 km.

CHAPTER 4. DAMAGE TO BUILDINGS & OTHER STRUCTURES

This section provides a critical appraisal of seismic resistance of widely practiced construction techniques by studying the differences between the observed and the expected behaviour and damage pattern of the built environment. A review of prevailing construction practices with respect to their seismic resistance is presented. The structural deficiencies of these construction types have been identified which led to their unsatisfactory response and widespread damage. Non-compliance to the earthquake-resistant construction features, as well as poor construction practices for locally available building materials were responsible for the majority of structural damage observed in the earthquake-affected area.

The region affected by the Chamoli earthquake is mountainous terrain where the settlement is dense in river valleys and sparse on hill slopes. Rising demographic pressure has been responsible for new settlements on hill slopes and in the areas which were once regarded as unsafe for building houses. Major civil engineering projects in the area are highways, bridges, small dams and micro hydro-electric projects and a few multi-storeyed reinforced concrete (RC) framed buildings. The housing units are largely low rise stone masonry load bearing types with diaphragms varying from pitched flexible roofs to rigid RC slabs for floors and roofs.

4.1. BUILDING CONSTRUCTION MATERIALS

Both in the Indian and Nepalese part of earthquake affected area, the most common building material for wall is rubble stone in mud mortar; timber, earth for floors; timber, mud and slate for roof construction. Cement, steel bars, clay bricks and corrugated galvanised iron (CGI) sheets are relatively new construction materials and their use is growing in urban / market areas and along the highways as these materials are to be transported from the plains. In Indian side their use is more common than in Nepal. The quality of sand used in these constructions is poor. The new construction materials and technologies have not reached in major part of the area. Use of concrete block is increasing in both Indian and Nepalese areas which are accessible by motorable road. Timber floors and slate covered roofs material are being replaced by RC slabs. No use of pre-cast RC sections was observed in building construction. In general, the quality of the concrete and other construction materials is poor, even for widely used masonry construction. For example, the importance of curing is not well understood by most of local craftsmen, and even if understood, it is rarely practiced in high reaches where water is in scarcity.

4.2. BUILDING TYPOLOGY

Majority of buildings are box type (load bearing stone, brick or concrete block masonry) and have suffered more damage than weak RC framed (with infills) types which, though very few in number, have performed extremely well, even in the regions of high shaking. The seismic performance of load bearing masonry structures depend heavily on the structural characteristics (strength, stiffness and ductility) of surrounding walls and diaphragms. They rely on walls to resist in-plane and out-of-plane inertia forces and on the diaphragms (floors & roofs) for not only to resist the shear forces but also to distribute the forces to vertical elements (walls) and maintain the integrity of the structure.

Majority of buildings in earthquake stricken area of both in Nepal and India, are constructed of rubble stone in mud mortar with heavy timber floor and slate roof. Use of corrugated galavanized iron (CGI) sheet roofing is on increase. Stone, brick or solid concrete block in cement sand mortar, and cast-in-situ RC slab buildings and RC framed buildings are few in numbers, especially in urban areas or places accessible by motorable roads. Despite existence of a good set of Indian and Nepalese Standards on earthquake–resistant design of buildings, majority of building structures are seismically deficient because the standards are rarely practiced. Majority of residential units which are minor construction and usually non-engineered are without earthquake-resistant features despite the availability of comprehensive guidelines for satisfactory earthquake performance in both countries. Various types of material and construction techniques that have been prevalent in the affected regions for walls and diaphragms are described in the following paragraphs.

4.2.1. Stone Masonry Walls

Stone masonry is produced from a wide range of materials and constructed in many different forms which have shown varying degree of performance in the Chamoli earthquake. Unreinforced stone masonry is very durable even in the hostile environment and has accommodated movements and resisted natural forces without becoming unstable and falling apart. Common rock types which are used for building construction in the affected region are sandstone, limestone, quartzite and slate, which are internally very durable building materials. However, some forms of stone masonry construction are extremely vulnerable to earthquakes.

4.2.2. Stone in Mud Mortar

In the affected area, rubble stone in mud mortar is the most common walling material. 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 (Figure 4.1). The resulting thin slender wythes behave as independent members, without any structural connection between the external and internal wythes. Many a times, the external wythes are constructed before internal wythes. Moreover, skilled masons work on external wythes where as novices hone their newly acquired skills on internal wythes. These buildings are up to two stories in height. Floor height in general is small (about 1.8-2.4 m). Often walls are plastered in very artistic manner that gives a false impression of ashlar masonry. Dressed stone in mud mortar is also rarely used. The stone masonry prevalent in the affected areas can be broadly grouped in the following two categories based on construction forms:

Stone and slate masonry

As seen in old houses, traditionally, the stone masonry is laid in mud mortar which contained large amount of clay and a "course" is made up of large sizes of stone blocks sandwiched between many thin wafers (2 to 5 mm thick) slates arranged in layers (Figure 4.2). These thin wafers of slate are filled in the depressions of large stones to create an "even" course and finished outer (exterior) surfaces as shown in Figure 4.3. The resulting stone masonry is different from typical random rubble (R/R) masonry. The wall thickness can vary from about 450 to 750 mm consisting of two wythes each of 200 to 300 mm thick separated by filler material. The filler material is loosely packed small stones and slates embedded in mud mortar. In well-constructed houses where quality of workmanship is good, throughstones are also used frequently to bind both wythes.

The damage to such masonry has 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 stones and in some cases, the mud mortar is being replaced with weak cement-sand mortar. These masonry walls have experienced more damage, however, the use of cement-sand mortar has helped in many cases.

Random Rubble (R/R) stone masonry

In general, Random Rubble (R/R) stone masonry has no layers of thin slates to fill in the undulating contours of large stones to create even "courses." 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. Sometime exterior surfaces, especially of government buildings, are decorated in such a way that they give a false impression of Ashlar stone masonry in which stone masonry units are dressed stone blocks laid in relatively thin layers of mortar (Figure 4.3). This practice of R/R masonry is not "indigenous" to hill areas and seemed to have migrated from the plains during the colonial period. Most of government buildings, hospitals, schools, jails, etc., built during this period suffered heavy damage especially when the structure is old. The collapsed walls of Chamoli jail are one such example which left 7 dead and 11 seriously injured (Figures 4.4 and 4.5).

4.2.3. 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.

4.2.4. Clay Brick and Concrete Block Masonry Walls

Fired brick and cement concrete blocks are rather new building materials in the area. Cement-sand mortar is used in these walling units. Their recent use appears to have been encouraged by Uttarkashi (1991) and Latur (1993) earthquakes, where stone masonry walls have shown poor performance and were responsible for large 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 4.6). In general, clay brick units are much weak compared to stones and shear failure of brick masonry walls was noticed which developed familiar X or diagonal cracks. Almost all brick buildings which used RC slabs for roofs and floors; have beams and columns though not necessarily capable of developing frame action; and/or have lintel and roof bands; have performed satisfactorily, even when bricks walls themselves are weak.

Many factors have contributed to growing usage of concrete blocks (Figure 4.7) 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. 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 225 mm x 150 mm. Concrete blocks are laid in cement-sand mortar and are used in load bearing as well as infills in weak RC frame construction. Very minor damage to such masonry walls was observed.

4.2.5. Light Reinforced Concrete Frame

There are a few RC buildings in the damage area surveyed mostly 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 or follow the construction of masonry infill walls. Behavior of these buildings will be more like hybrid structure, 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.

Frames are usually light with column size 230x230 mm with four to six number of 12 mm diameter reinforcing 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 (Figure 4.8). The columns spacing in each principal direction of the building varies from 3 m 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 roof are constructed of cast-in-situ RC slab.

4.2.6. Diaphragms in buildings

Flexible Diaphragms

Pitched roofs have been the most popular choice for buildings. However, there are many variants of pitched roofs with varying degree of observed seismic performance. In low cost houses, especially in rural areas, the roofs are either composed of wooden joists and planks or simple wooden trusses and rafters (Figures 4.9). In general, very good quality of timber materials from trees like *Chir* and *Deodar* have been used. In some cases, branches from shrubs of *Ringal* and *Kail* are placed over rafters to support a layer of mud which is then covered by thin pieces of slates to provide a water-resistant cover (Figure 4.10).

Slates are most common roofing material which are 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 government buildings, wooden planks are placed on rafters to support the roofing material as shown in Figure 4.11. Corrugated Galvanized Iron (CGI) sheets have also been used as a roofing material in many cheaply built school buildings.

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 width in order to protect it from rain.

These diaphragms are inherently weak in shear and can not tie the walls together even when they are properly connected to them. They are heavy when slates are used attracting large inertia forces and often slates were observed to be dislodged even when the roof supporting structure survived the shaking. 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 truss itself due to failure of joints and/or members forming the truss or other roof supporting structure (Figures 4.12 to 4.14).

Rigid Diaphragms

Flat cast-in-situ reinforced concrete slabs are recent substitute for old fashioned pitched roofs and wooden flooring systems. These slabs are relatively rigid and have sufficient strength and stiffness. No failure of such slabs was noticed, however, often cracking in walls at the bottom level of slab was observed which is an indication of the relative displacement between the slab and the wall due to lack of connection between them. This lack of positive connection somewhat diminishes the beneficial effect of rigid diaphragms in enhancing the overall structural integrity.

4.2.7. General layout of buildings

A typical residential unit is compact and openings for doors and windows are generally in the front wall and are small. In few buildings CGI sheet has replaced traditional slate and earth in roofs. And in few other timber floor and roof structure is replaced by RC flat slab keeping the similar building plan and elevation because they are more determined by functional requirements of the structure. RC slabs are new entrants as a building component in these hilly areas. Mixed construction is also common, i.e., a part of building in traditional material and technology where as new additions use more modern materials. No anchorage or any other mechanism is used for integrity of walls, floors or roofs. As a result the building components are poorly connected and under lateral loads behave as if they are stacks of building materials. A typical construction of stone-mud buildings on Indian and Nepalese areas are shown in Figures 4.15 and 4.16. Figure 4.17 shows major house types in the earthquake-affected area.

4.3. BUILDING BEHAVIOR AND DAMAGE PATTERN

4.3.1. General Damage Pattern

The damage in earthquake affected area was mostly concentrated in R/R stone masonry buildings. The general sequence of damage being the collapse of bearing wall followed by collapse of heavy floors and roof. Sliding and falling of roof slates were also reported. The collapse of such buildings have been sudden due to the lack of ductility of the walls against the lateral loading, weak construction materials and poor technology of wall construction in general, and lack of integrity of structural elements. It was evident that damage to a building was largely influenced by its walling material. Damage were limited to minor cracking in buildings which used cement-based materials in the construction of its vertical elements, such as cement-sand mortar for masonry and/or RC columns in framed buildings

Buildings with weak masonry but with reinforced concrete slab as floor or roof suffered relatively less damage. These buildings suffered delamination of bearing walls especially in near floors and roofs, severe diagonal cracking, and opening up of corners. In general, buildings with flexible floor and roof suffered more damage in upper stories. Out of plane failure of gable walls and other cross walls were common caused by the bending of walls. Buildings with RC slab (rigid diaphragm) suffered more damage in walls of the first storey due to insufficient shear strength (diagonal tension cracks).

4.3.2. Seismic Resistance Mechanism of Masonry Structures

The majority of masonry structures use the unreinforced masonry walls as bearing and enclosure walls. These masonry structures can be viewed as box-type structures in which the primary lateral resistance against the earthquake forces is provided by the membrane action of the diaphragms (floors and roofs) and bearing walls.

In the event of earthquakes, the ground motion is transmitted from the foundation to the end walls acting as in-plane structural walls whose response to the motions depends on height, wall stiffness and contributory masses from the floor diaphragms. At a given elevation these wall response motions act as input motions to the floor diaphragms, which resist the resulting inertia forces through their in-plane shear strength and integrity with the vertical elements. If the diaphragm is rigid, the response at all points along the floor will be equal to the end-wall response. However, if the diaphragm is flexible, as will often be the case for the existing masonry structures, the response may well be modified from the end-wall values. The response of the diaphragms in turn becomes the input motion for the URM walls in the out-of-plane direction. The out-of-plane walls resist the resulting inertia forces and maintain stability through the flexural action as observed in vertical beams. The above described behaviour of masonry structures and the flow of seismic energy is illustrated in Figure 4.18.

Since the ground motion is modified by the actions of the end structural walls and of the diaphragms before acting as an input motion to the out-of-plane wall, the in-plane response of the masonry end walls directly affects the kinematic inputs to the walls and to the end of the diaphragms. Clearly, a rigid masonry wall would deliver larger accelerations to the diaphragms than flexible and ductile end walls, and the amount of amplification depends on the site soil conditions and on the aspect ratio of the wall. However, the lateral (in-plane) deflections of flexible diaphragms are large, as a result, weak bearing walls can be easily pushed out-of-plane jeopardizing their stability.

Further, it is very important that the all the components of masonry structures are tied together so that they can act together as one unit in resisting earthquake induced forces. If walls move inwards or outwards, diaphragms (roof and floor structure) will lose support and collapse. The lack of proper connection capable of withstanding compression and particularly tension at the following locations have been responsible for damages to number of buildings: between the perpendicular walls at corners for peripheral walls, between walls and cross-walls or return walls and between the walls and the diaphragms as shown in Figure 4.19. Lintel and/or roof bands provided in peripheral and cross walls tie up the walls together and enhance its overall structural integrity as seen in many past earthquakes where such structures sustained expected minor damage even under significant shaking.

The interactions implied by above- mentioned behaviour of masonry structures in resisting earthquake loads are rather complex in nature, and highly inter-dependent on various constituting elements. This gives rise to many different failure mechanisms for masonry structures as discussed in the following section.

4.3.3. Damage to Masonry Buildings

Stone-mud buildings with flexible floors and roof

The typical pattern of damage for stone masonry buildings with flexible floor and roof included wall corner failures, separation of wythes, collapse of gable walls, collapse of wall, dislodging of walling material, bulging of walls and collapse of diaphragms (floors and roofs).

Wall corner separation: One of the major causes behind the large-scale damage was lack of positive connection between perpendicular walls. Separation of corners was frequently through out the affected area. Due to this weakness, the walls behaved as independent component rather than a box. Figure 4.20 shows such a separation of walls at corners in a damaged stone masonry building. Many a times external walls are constructed first and internal walls (cross walls) are added afterwards without any connection between them. In general, the importance of integrity of perpendicular walls is not recognized.

Separation of wythes: Majority of R/R stone masonry buildings suffered due to this deficiency which was noticed in many forms such as swelling or bulging of walls, vertical cracking from bottom to top of wall in end walls along the thickness. Figures 4.21 shows partial collapse of one wythe while the other is still in place and carrying vertical load. The walls may bulge out (swelling) after the wythes get separated as shown in Figure 4.22. This deficiency arises from the manner in which the wall is constructed. Both wythes of the walls are raised independently and the intervening gap is loosely packed with small stone pieces and mud. As a result, there is no structural connection between wythes. The use of through stones to bind individual wythes is rare even in new constructions. (Figure 4.1).

Out of plane failure of walls: Gable walls are one of the most vulnerable components of a pitched roof building unless they are well integrated with rest of the building. Frequent collapses of gable walls were observed in the affected area. These tall walls become slender (i.e., large height to thickness ratio) and become vulnerable to out-of-plane actions. Figure 4.12 shows collapse of gable wall causing total collapse of roof of a classroom building of Government Inter College at Bairgana. Figure 4.23 shows a typical collapse of gable wall.

Out of plane collapse of walls other than gable walls was also common. The long and tall walls not well connected with perpendicular walls, floors and roofs primarily behave like free standing walls and can fail due to out of plane instability as shown in Figure 4.24. In many cases the out of plane instability of walls resulted in tilting of walls, especially in mud-stone buildings with flexible floor and roof.

Lack of structural integrity: Floor and roof structures usually "sit" on bearing walls without any positive connection and face no serious problem in resisting gravity loads. Due to this lack of connections diaphragms (floors & roofs) can not restrain walls from out-of-plane movement nor maintain their own integrity during shaking. Further, very flexible diaphragm with inadequate shear capacity can not distribute shears to different vertical elements of the structure. Figure 4.25 illustrates a partial collapse of building due to lack of structural integrity.

In-Plane Shear strength of wall: Poor in-plane shear performance was observed in many mud-stone buildings. It was primarily due to weak in-plane shear strength of the walling material and construction technology rather than due to presence of large openings. In fact, openings in mud-stone buildings are rather small and few in number. Diagonal shear cracking of wall piers was common in earthquake stricken area. Where opening were present cracks in generally started from the corners (Figure 4.26).

Stone-mud Buildings with Rigid Floors and Roof

These buildings performed far better than mud-buildings with flexible floor and roof because, rigid floors and roofs "tie up" peripheral walls as a result the building perform as one box structure. Due to in-plane rigidity of floor and roof, the seismic force is distributed to piers proportional to their stiffness. These buildings also suffered damages such as separation of wythes especially in upper part of walls, severe diagonal cracking, corner separation, out of plane collapse of walls but the intensity of damage was far less.

In-plane shear strength of wall: As discussed above, this walling material is weak in shear. As the floors and roofs are rigid in character these distribute the lateral load to piers in proportion to their stiffness. This compels piers parallel to the vibration carry more force, which leads them to shear cracking. Figure 4.27 shows racking shear crack in a pier next to an opening. These cracks generally open from corners of discontinuities such as door and window openings. More cracks were observed in first storey walls where shear force demand is higher than upper stories.

Delamination of wythes: These buildings also suffered from separation of wythes, however, it was less severe than building with flexible diaphragms.

Buildings with brick or block masonry walls laid in cement-sand mortar and with rigid diaphragms

No notable damage to these buildings were observed or reported in the area. Minor to moderate in-plane shear cracking of piers were observed especially in brick masonry walls which are weakened by openings (Figure 4.28). Typically concrete block units are stronger than brick units and if the mortar is same, block masonry walls have greater shear strength.

4.3.4. Damage to RC infill framed buildings

No noticeable damage to RC frame buildings was seen or reported in earthquake affected area although the frames are light and construction quality, in general, is poor. A few brick in-fill walls suffered separation from the main frame in a hotel building in Pipalkoti. This damage was localized in central area of the building where the atrium was located.

4.3.5. Configurational Problems

In general buildings were nearly symmetrical in plan and elevation in earthquake affected area. However, those with significant asymmetry suffered damage. Pounding damage in row houses were also observed where the separation gap was not adequate (Figure 4.29). Other configurational problems included non-parallel vertical systems for corner buildings (Figure 4.30), accumulated damage in lower storeys of houses on slopes (Figure 4.31), and incompatible distortions at reentrant corners, etc. These buildings suffered damage despite their good quality of construction.

Plan Asymmetry

Asymmetrical distribution of mass and lateral stiffness caused considerable damage in a few buildings due to torsional forces. One example is temple of Shivnath Kedar of Shivnath in Nepal as shown in Fig 4.32. The temple is sited on a flat, large hill top terrace. The main building is octagonal in plan and constructed of well dressed stone in mud mortar. Very little mud is used for mortar. The building is small and compact and the quality of construction is good. The building is annexed with a verandah which is a timber structure with slate roof. The verandah is supported by timber stilts which support ridge and eaves beams. The ends of these beams are anchored in stone masonry of main building. During shaking the inertial forces would have caused the flexible structure of verandah to deflect more than very stiff main building. This deformation incompability will cause stiffer main building to resist a larger share of lateral forces. Masonry walls of the main building developed wide cracks whereas verandah structure escaped with no noticeable damage. (Figure 4.33).

Setback in Elevation

The vertical distribution of mass of a structure should lie, as far as possible, in one vertical plane. Construction of setbacks in upper stories gives rise to torsional forces as a result the stories below can suffer considerable amount of damage. Damage to one such structure is shown in Figure 4.34. The building is constructed of semi dressed stones in mud mortar with cast-in-situ RC slabs. It is two storey in height and is provided with RC lintel band. In the second storey only two rooms were constructed leaving an open terrace in the front. Due to this setback construction, the mass centers of two stories do not lie in a line causing severe torsional modes of vibrations. Torsional forces were strong enough to rotate the floors, as a result one the corners even shifted horizontally about 40 mm causing severe damage to the recently built structure. However, no damage was noticed in the second storey.

4.4. DAMAGE DUE TO SECONDARY HAZARD

Damage due to secondary hazards such as rock fall in worst affected area were also observed. A one storey building in Sirokhoma village along the river

Balganga suffered severe damage to its walls and roof when a huge boulder falling from the opposite cliff hit it. The damaged house is shown in Figure 4.35.

4.5. DAMAGE IN EARTHQUAKE AFFECTED AREA

In the following an area-wise description of damage due to the earthquake is provided. The objective is to illustrate the effect of housing types, the local site conditions, economic well off the community, etc. on the performance of structures.

4.5.1. India

Bhatwari Sunar

Bhatwari Sunar village is located on a flat river terrace of Mandakini river near Chandrpuri on the highway to Ukhimath. Majority of building is constructed of stone-slate masonry in mud mortar with heavy flexible floor and roof. A few recent constructions used flat cast-in-situ RC slab for floors & roofs. Many village buildings suffered moderate to severe level of damage and almost all of them suffered some sort of damage. Building structure in the village were oriented in predominately east-west direction. Walls along east-west direction suffered more damage due to out-of-plane instability, suggesting that significant component of seismic excitation was in the north-south direction. Walls of upper stories were worst affected which led to collapse of roof in many cases. Buildings also suffered in-plane shear failure which was easily recognized by diagonal tension cracks which were wide open. As the roof and floors lacked integrity, shifting of roof and false ceilings rafters were also observed which resulted in collapse of roof or false ceiling.

Chandrikapuri

Chandrikapur village is located just across the Mandakini river opposite of Bhatwari Sunar village on the lower river terrace. The building stock in this village is same as that of Bhatwari Sunar but the damage to buildings in comparison were much less. All dwellings in this village are constructed of stone in mud mortar with heavy flexible floor and slate roof. They suffered only minor damage (Grade G2).

Kansil

This village is located on a steep sloping terrain some 12.5 km off the main highway to Ukhimath near Chandrikapuri. Majorities of building are constructed of stone in mud mortar with heavy flexible floor and slate roof out of which some 70% suffered severe to destructive level of damage. All the buildings suffered damage in downhill side, i.e., front of the building (Figure 4.25). In general, front and central tall walls of upper storey in many and of bottom storey in a few failed due to out-of-plane failure leading to collapse of roof and floor. One storey houses in stone in mud but with cast-in-situ RC slab roof also suffered severe damage. Buildings also suffered from diagonal shear cracks which were wide open. Separation of roof slabs from the supporting walls was also observed. Flexural cracks were clearly visible in masonry piers.

Mandal

This village located on a gently sloping terrace of Balkhila river valley very close to foothills and it is on highway connecting Chopta to Gopeshwar. Majority of buildings suffered minor damage to partial collapse. A college hostel building suffered out of plane failure of gable and cross walls as well as severe delamination of wythes and separation at corners. One storey building of Government Allopathic Dispensary constructed of large stone boulders in mud mortar with wooden joist and plank roof system suffered severe damage due to delamination, corner separation, spalling of walling material from above the lintel, and failure of gable wall (Figure 4.36). The dispensary building was provided with lintel band but its reinforcement were not anchored in perpendicular walls. The building seemed well constructed with good aesthetics. One to two storied five buildings in the same complex constructed using stone or brick in cement mortar with floor and roof made of cast-in-situ reinforced slab suffered non to very minor damage.

Bairgana

Government Inter College complex consists of seven one-storeyed buildings, out of which roof of one building collapsed due to collapse of gable wall (Figure 4. 12). The building was constructed of stone in mud mortar with CGI sheet roofing. Other buildings constructed of stone in mud with CGI sheet roofing or RC slabs suffered from cracking of walls and corner separation (grade G1 to G2). A building in brick in cement sand mortar with RC slab did suffer from in-plane shear cracking in piers (Figure 4.28).

Gopeshwar

Gopeshwar is headquarters of Chamoli district and is situated on a hill slope. Buildings constructed of stones in mud mortar with flexible timber floor and slate or CGI sheet roofing suffered minor to severe damage (grade G1 to G3). Major damage observed included cracking and bulging of walls and falling of walling material. Interestingly, three to four storied buildings in Gopeshwar market area along the steep slope did not suffer any damage. These buildings were constructed using modern materials, i.e., fired clay brick, concrete blocks or stone in cement-sand mortar and reinforced concrete.

Mawan

Mawan village is reported to be in epicentral area. It is situated on a ridge carved out by at the confluence of Birganga and Balkhila rivers. On a terrace close to a retaining wall, three houses in this village were severely damaged. They all used stone in mud mortar for wall and two were provided with RC slab for roof and one had slate roof. The buildings with RC slab suffered partial collapse where as the one with slate roof suffered total collapse. The building with RC slab suffered severe shear cracks of piers, dislodging of walling material and partial collapse of wall (Figure 4.22). Due to compaction of backfill soil and shifting of retaining wall, the stone staircase leading to roof of one of the house tilted and shifted

Chamoli

Chamoli city which is one of the worst-hit areas, is located on different terrace levels of Alakhnanda river. The topography is relatively flat to mild sloping. Construction type is mixed. Buildings in lower Chamoli market are rather old. Majority of old buildings is constructed of stone in mud mortar with heavy flexible floor and roof and a few with CGI sheet roofing or cast-in-situ RC slab. Relatively new buildings are constructed of fired brick, concrete block or stone in cement sand mortar or RC frame. Many buildings constructed of stone in mud with flexible floor and roof suffered severe to destructive level of damage, and all suffered minor level of damage. Such buildings with rigid floor and roof also suffered partial collapse (Figure 4.30). These buildings suffered damage due to out of plane failure of walls, delamination of stone walls, corner failure, and wall bulging, dislodging of walling material etc. A classical example of delamination was observed in Chamoli Jail. Non to minor damage was suffered by buildings with modern materials.

Pipalkothi

This town is located along the highway, 7 km from of Chamoli on the way to Josimath. The damage was concentrated in old part of Pipalkothi. This settlement is situated close to a steep hill slope underlain by an old natural cave. Buildings constructed of stone in mud mortar with flexible floor and roof suffered severe damage to destruction. The weak masonry buildings suffered from delamination (bulging), wall cracking and separation of corners. A two storied building constructed of brick in cement sand mortar with RC slab suffered severe damage as it was pounded by a collapsing adjacent old masonry building (Figure 4.29). The building shifted about 20 mm due to impact. Newly constructed buildings in fired brick or concrete blocks in cement sand mortar with RC slabs suffered minor shear cracks.

Ghingrana

This village is located about 7 km from Gopeshwar on a gently sloping terrain. Only a few (five to six) buildings totally collapsed out of about 100 buildings while other suffered minor to moderate level of damage. Majority of buildings is constructed of stone boulders in mud mortar with flexible floor and roof. Newly constructed buildings are in solid concrete block masonry laid in cement-sand mortar and cast-in-situ RC slabs for diaphragms. The basic causes of damage were: out-of-plane failure of walls and gables, separation of wythes, minor to severe flexural and shear cracking of walls and connection failure. In a damaged building, the floor slab was sitting partially (about 150 mm) over 450-mm thick wall.

4.5.2. Nepal

The team visited four districts of Kanchanpur, Dadeldhura, Baitadi and Darchula in far-western region of Nepal adjacent to the Indian Territory. Comparatively more damage was observed in Dadeldhura and Baitadi than in Kanchanpur and Darchula. Physiographically Dadeldhura and Baitadi are in the same mountain range as Garhwal region of India. The location of the affected areas, observed or reported in Nepalese territory is presented in Figure 1.1. Damage in Nepal side is sparse and localized. Generally damages are concentrated on hill tops, ridge ends, and steep slopes. The observed damage ranged from minor cracking of walls to partial and full collapse of rubble stone buildings. No damage was observed in buildings other than stone building.

Dashrath Chand Municipality, Baitadi

Old part of this hill town is located along a hill ridge oriented in east-west direction. Southern cross slope of the ridge is rather steep where as northern one is relatively flat and that is where the town is expanding. Majority of buildings are constructed of stone in mud mortar with heavy flexible floor and roof whereas a few have cast-in-situ RC slabs. Buildings are generally one to two storey. New buildings have more than two storeys and stone masonry walls in cement sand-mortar with RC slab.

Many buildings here suffered minor cracking (grade G1 to G2). District Post Office constructed of stone in mud mortar with flexible floor and CGI sheet roofing suffered partial collapse. A one storey school building, with stone in mud mortar and CGI sheet roofing suffered corner separation of walls, cracking in floor and sliding of floors in all rooms in down hill side noticeable through cracking at the interface. Other building in mud mortar suffered minor diagonal cracking, vertical cracking, and corner separation. A few buildings in mud mortar with RC floor and roof, suffered diagonal and vertical cracking. Stone masonry buildings with good quality construction suffered minor damage.

Basadi, Shiv Nath, Baitadi

This village is located along a steep hill slope. Here all buildings are in stone with mud mortar with flexible timber floor and slate roof. Buildings are generally two storey. Floor height is around 1.8m (6'). More than 20% of buildings suffered more than cracking (G2). One building suffered severe cracking and partial collapse (Damage grade G4). One interesting thing observed here was, damage was concentrated along a strip across the hill slope. Cracking of the ground was also reported in this village but it can not be observed may be because of time gap (the team visited the area after 3 months of the event), rainfall.

Melauli, Baitadi

In this village the damage was primarly concentrated along the top of a hill ridge and no damage was reported or observed just below the ridge top or in its periphery. The stone masonry houses used irregular rubbles in mud mortar with slate roof or CGI sheet roofing. In the village out of nine buildings two suffered destruction whereas others suffered from corner cracking, wall bulging, diagonal cracking, vertical cracking below windows, and separation of wythes. The health post building is made of dressed stones with very little mud and in general, has good quality of construction. No damage was observed in the building despite the fact that it has no earthquake resisting features.

None to minor damage was observed or reported in Dehimandu, Durgasthan, Maharudra, and Salena VDCs located on the way from Dasrath Chand Municipality to Sirad. Some minor damage was also reported in Durga Bhawani, Gurukhaul, Shreekot, Shitad, Rim VDCs of Baitadi district.

Bagarkote, Dandeldhura

This VDC is five hours away from the nearest roadhead, Dadeldhura, on foot. The damages were concentrated west of Thuli Gad. In Ratani, both houses suffered severe to partial collapse. They were located close to the end of a narrow ridge having very steep cross slopes. These two storeyed houses were constructed of rubble stones in mud with flexible timber floors. One of the houses with slate roof suffered partial collapse whereas the other one with thatch roof suffered severe damage (Grade G3).

Matela, another village of Bagarkote VDC

This village located along a narrow ridge with steep cross slopes (65 to 70 degrees) experienced minor to severe damage (Grade G1 to G3). Majority of buildings are made of stone in mud mortar with flexible timber floor and slate roof. Significantly less damage was observed in buildings with dressed stones.

Khalanga, Darchula / Mahendranagar, Kanchanpur

Khalanga is headquarter of Darchula district and its market center is situated on river terrace of Mahakali river. The terrace is relatively flat and the settlement is at the foot of a steep cliff. Buildings here are similar to Dasrath Chand Municipality. Buildings constructed in stone in cement mortar suffered fine cracks whereas buildings in mud mortar suffered bulging, wide cracks, and partial collapse of wall. A school building suffered corner failure, wide cracks, and partial collapse of wall. Some damage was also reported in Lali VDC. Some minor damage has been observed in Mahendra Nagar Municipality and Daijee VDC of Kanchanpur also.

4.6. SEISMIC EVALUATION OF SCHOOL BUILDINGS

One of the objectives of this visit was to verify the *vulnerability functions* developed for School Earthquake Safety Program of the Kathmandu Valley Earthquake Risk Management Project (KVERMP). In Chamoli earthquake the damage was concentrated in stone buildings only and there were many parameters controlling the extent the observed damage. This study provided a good database, which in connection with damage data from other earthquakes in different region could be used in developing vulnerability functions.

CHAPTER 5. DAMAGE TO LIFELINES

5.1. ROADS & BRIDGES

The area has a large number of highway and pedestrian bridges over rivers, rivulets, and gorges. The highway bridges are made from a variety of materials (steel, reinforced concrete and stone masonry) and of various configuration and forms (trusses, T-beams and girders, arches). No damage to any of the highway bridges was noticed. Even older stone arch bridges have suffered no damage (Figure 5.1). Most of pedestrian bridges were of suspension types and no particular damage to the bridge structure or to the supporting pylons was noticed. However, in a particular instance near Chandrapuri some overstressing of old stone masonry pylons was noted. Another pedestrian steel truss bridge over Balkhila River near Sirokhoma village suffered local damage to deck and railings when it was hit by falling rock from the adjacent cliff (Figure 5.2).

Fissures on roads were noticed at places which were primarily due to ground movement across unstable slopes. At many places boulders from hill slopes which were steep and consisted of fractured rocks came down and obstructed hill roads (Figure 5.3). In Lower Chamoli area, shoulder of the main road was badly damaged when the side slope collapsed. Figure 5.4 shows the construction of a reinforced stone masonry wall to retain the subgrade.

5.2. DRINKING WATER SUPPLY

In many areas water pipelines were disturbed by the ground shaking and the supply of the drinking water was affected. This disruption was primarily concentrated in the areas of heavy shaking.

CHAPTER 6. RESCUE, RELIEF & PUBLIC RESPONSE

6.1. INTRODUCTION

The Chamoli Earthquake of 29 March 1999 caused widespread devastation in Chamoli, Rudraprayag, Tehri, Pauri-Garhwal and adjoining districts of Uttar Pradesh, India. The earthquake was felt at Dehradun, Haridwar, Saharanpur, Moradabad, Bijnore, Muzaffarnagar, Meerut, Ghaziabad, Srinagar and adjoining areas in Jammu and Kashmir, Punjab, Himanchal Pradesh, Haryana and Rajasthan.

This earthquake was also felt in the Nanda Devi mountain area on the Sino-Indian border and in four districts Kanchanpur, Dandeldhura, Baitadi and Darchula of western region of Nepal.

In the following sections a brief account of emergency response of government agencies, NGO's and voluntary organizations, and public response is presented. These observations are based on the team members' interaction with residents (Figure 6.1) and civil administrators of the affected areas.

6.2. RESPONSE OF THE GOVERNMENT, INGOS, NGOS AND OTHERS

6.2.1. Rescue & Relief

The district administrations mobilized their resources immediately after the earthquake. The effort apparently was to provide food, sheltering materials and other essentials to the victims in the affected areas. Lantern, blanket and other goods were distributed in the affected areas. Tents, plastic sheets and tarpaulin were also distributed. Efforts were made to provide relief to the affected families in the inaccessible areas through helicopters by air-dropping the relief materials. The respective District Magistrates made appeals to NGOs to contact the administration for sharing the work of distributing relief materials. Control rooms to monitor and co-ordinate relief operations were established in Rudraprayag, Ukhimath and Jakholi.

The relief assistance provided to the families of the dead victims was a considerable amount (Rs. 50,000 to 100,000. Each family that suffered from the earthquake received Rs. 1000 and 10 kg rice and 10 kg wheat flour per head. According to the District Magistrate of Chamoli district 1000 metric tons of CGI sheets shall be distributed to the victims. Eight CGI sheets (10x12 ft in size) were provided to those victims who had lost their houses. It was also planned to construct 800 residential buildings for the victims which could accommodate 50% of rendered homeless in this earthquake. Many government organisations provided tents and tarpaulins for temporary shelter. Border Roads Organization cleared road blocks caused by landslides on important roads.

In Nepal also disaster victims have been provided relief assistance as per the norms specified by His Majesty's Government of Nepal

6.2.2. Constraints in rescue & relief operations

Rescue and relief operations were inadequate and late largely due to non-preparedness on the part of the people and the lack of effective emergency response system of government agencies. :

Lack of Resources: The local administration did not have adequate manpower and sufficient resources to carry out relief works immediately in all the affected areas.

Poor accessibility: The worst affected areas of Chamoli and Rudraprayag districts are mountainous region making effective rescue and relief operations a very difficult task. Large parts of the affected area were inaccessible due to landslides for a couple of days following the earthquake. In these areas the response team could approach the affected villages after several days. In this situation rescue and relief works were carried out by the local people themselves according to their ability. The NGOs and voluntary organizations kept their relief activities near motorable roads while people living in the far-flung mountainous areas did not get any help for several days.

Timeliness: The people of the disaster area reported that rescue, relief and medical treatment of the victims was not very prompt and effective. Rescue teams were able to go only a few hours after the earthquake even in the areas in district headquarters and on roadside.

Inadequacy: The relief materials such as food, tents and shelter materials and medical support were insufficient. Especially, the tents were not available in sufficient numbers, as a result, 15 to 16 persons were seen using a single tent (Figures 6.2). Moreover, the tents were old and torn. Air dropped food packets were also not adequate.

Wild animals: People in temporary shelters were exposed to likely attack from wild animals of prey and poisonous snakes. People spotted wild animals roaming in the villages.

6.2.3. Public Response

Frustration, dismay and anger among the earthquake affected population was widespread. The general complaints were:

- rescue, relief and treatment of the victims was not very prompt, effective and timely.
- relief materials were not sufficient and in some cases did not reach the needy
- relief materials were misused in some cases, and
- no relief reached in a few remote areas for several days
- no protection from wild animals in temporary shelters and from landslides

People of the affected area were still mentally upset and reported emotional stresses even after a month. Some of these victims lost their family members and friends. The emotional stresses caused by injuries and loss of relatives can be far more serious than loss of physical property. However, no psychological counseling was provided to cope with these emotional disturbances so that they can resume their normal life as soon as possible.

The following quote from Hindu Newspaper (April 1, 1999) which a statement of Mr Bhupati Lal, a resident of Makku, perhaps sums up the sentiments of the victims:

> *"I have lost my double storied house and two children. I don't have clothes or food or proper shelter. Still no one is bothered. All that the Government has done is give me Rs. 500 as relief grant," he cried aloud, saying what he needed was a house to live in along with the remaining members of his family. "The sher" (wild cat) is on the prowl and we don't know how long we will survive in this torn tent," he wondered.*

Many local, regional and national newspapers as well as other media also commented upon the poor government rescue and relief works in the affected area. Some of the headlines which appeared in newspapers were: *"Victims complain of poor relief"* (The Hindustan Times, March 31, 1999), *"Shaken victims of quake watch rescue work crawl*" (The Indian Express, March 31, 1999) and *"Quake victims in Garhwal still awaiting Government relief"* (The Indian Express, April 6, 1999). The Indian Express further elaborates that *"Despite tall claims by the state government officials, even after a week of the devastating earthquake which hit the Chamoli and Rudraprayag districts of Garhwal, killing more than a hundred people and rendering thousands homeless, the victims in the villages are still awaiting government relief* !

CHAPTER 7. RECONSTRUCTION, REHABILITATION OF DAMAGED BUILDINGS

A very brief account of the measures undertaken for reconstruction and rehabilitation of damaged houses in the Chamoli earthquake affected area is included here indicative of the strategies adopted for a successful rehabilitation program.

7.1. FIELD ASSESSMENT OF DAMAGES

The initial damage assessment was carried out in Chamoli and Rudraprayag districts immediately after the earthquake by the revenue staff. This revealed that 12306 houses were completely damaged and another 71333 were partially damaged. in Chamoli district. Also 7104 houses were totally destroyed and 14677 houses were partially damaged in Rudraprayag district. However it was later known that houses were destroyed and damaged in two other districts namely Tehri Garhwal and Pauri Garhwal. Also urgent action was taken by the Government to take help of Building Materials Technology Promotion Council (BMTPC), Housing and Urban Development Corporation (HUDCO) and Central Building Research Institute (CBRI) to arrange proper training of junior engineering personnel in the proper assessment of the damage. Accordingly about 500 persons were trained within a month of the happening of the earthquake, using the classification of damage as per MSK intensity scale given in Annexure 1. Through this detailed survey the following numbers of damaged houses emerged out (Report of Task Force, 1999):

Table 7.1 Damage to houses in Chamoli earthquake affected area

Name of District	**No. of Houses Damaged in Category**				
	G1	**G2**	**G3**	**G4**	**G5**
Chamoli	19487	21900	13757	2949	625
Rudraprayag	9126	12518	11500	5099	1008
Tehri-Garhwal	22825	29204	15356	3231	514
Pauri-Garhwal	7089	5731	2087	183	69
Total	**58527**	**69353**	**42700**	**11462**	**2216**

Comparing the numbers brought out by the revenue staff and trained engineering staff, large variations could be observed in the number. Grater objectivity in the assessment of damage was made possible by a Visual Damage Assessment guide prepared by BMTPC (1999). This survey guided the financial package declared by the State Government and the rehabilitation technologies to be adopted for repair, strengthening and reconstruction of damaged buildings.

7.2. SETTLEMENTS VULNERABLE TO LANDSLIDES AND ROCKFALLS

Besides the damage to houses and buildings under earthquake shaking, another matter of concern was the vulnerability of villages from the occurrence of landslides and rockfalls. The State Government has presently identified 16 such villages in various affected areas. However many more are vulnerable wholly or partially to such hazards either under the onslaught of monsoons or earthquakes, or their occurring simultaneously. The identification of such villages is to be done by the Geological Survey of India (GSI) and the Department of Geology of the Government of Uttar Pradesh. Other organisations like the University of Roorkee and Central Road Research Institute (CRRI) are looking into other issues like stability of slopes, soil properties, drainage profile, etc.

It was realised that the relocation of village is a sensitive issue requiring close coordination between all the concerned agencies like Department of Forest, Department of Environment, Department of Industries besides other land owning agencies of the Central and State Governments. The relocation process has to be taken up in association with the local communities, in case the same is to succeed. The new locations need to be decided looking into the requirements of the displaced communities with special reference to cluster planning to retain the existing economical and cultural linkages.

7.3. TECHNOLOGY PACKAGE FOR REPAIR, RETROFITTING AND RECONSTRUCTION

The rehabilitation of the damaged and vulnerable houses by repairing, retrofitting and reconstruction, using disaster resistant technologies, invariably calls for a package identifying the right choice of building materials coupled with appropriate building construction methods. The skills of the local artisans need to be upgraded so that they are able to effectively implement these technologies in the field. The community as a whole must also accept these changes that are required to make their dwelling unit disaster resistant. The resistance of the community to adopt any new technology can only be taken care of by providing them the complete information and by showing them that these indeed are beneficial to them and would protect them in any future incidence of earthquake.

Taking into consideration the above issues, seven Building centers have been established in the region to play a significant role by training the local artisans on the disaster resistant technologies in an effort to transfer the technologies developed by various R&D institutions to ground level applications. Nineteen demonstrations units constructed by HUDCO give a live example of the technologies and created much needed awareness in the general public. The various publications brought out by HUDCO and BMTPC in this regard contributed significantly towards this objective.

The design as well as implementation of the above mentioned demonstration units have attempted to accommodate the social and cultural needs of the people in the region like providing niches, shelves, lofts for storage, hooks on wall, hangar space requirements, living style, social economic condition etc. Locally available materials are being selected and traditional construction techniques incorporating, the earthquake resistant features, like plinth band, lintel band, roof band, vertical reinforcement at corners and wall junctions, 'through' and 'long corner' stones, etc., are being used for these demonstration units.

So as to achieve replicability of the building technologies, the Building Centers have so far trained 175 engineers and more than 600 masons. During the training the trainees were explained the reasons for damages and the need to make earthquake resistant buildings.

Besides the Demonstration Units, in order to make live implementation of the technologies for earthquake resistant building construction and the various repair and retrofitting methods, and also to make the people confident of the above, HUDCO adopted two Model Villages, one in Chamoli (Village Ghingarana) and one in Rudraprayag (Village Kansali) and one Model Basti at Gopeshwar and provided a grant assistance of Rs. 3.5 million for each model village and basti. The construction, repair and retrofitting work is being accomplished with full participation of the beneficiaries.

7.4. COMMUNITY BASED REHABILITATION

It was observed that over a thousand Non-Government Organisations (NGOs)and community action groups have been registered and working in the Garhwal region. Most of the NGOs have been involved in activities and social welfare schemes such as social forestry, watershed development, education, literacy, health, animal husbandry, horticulture and environment.

The role of NGOs in the community based rehabilitation process was considered important from the beginning, one of the main reasons being that such organizations are directly working at the micro level with and for the community. They are also accountable for their activities, not only to the donors but also to the target population. The NG0s working at local level can raise the confidence of the people in involving and managing the program / project activities and convince them about the need for change. This approach has indeed been greatly help in creating the proper awareness and environment for rehabilitation work.

7.5. FINANCIAL PLAN

Considering the various grades of damages observed in the earthquake and the cost of technology options, the State Government announced grant assistance of Rs. 25,000 for G5 category if reconstruction of the house is required, Rs. 15,000 for G4 category if retrofitting is considered sufficient, Rs. 7,500 for G3 category, Rs. 2,500 for G2 category and Rs. 800 for G1 category. The total amount works out to be Rs. 811.2 millions. Those beneficiaries who are below poverty line" will also receive Rs. 22,000 for the house reconstruction in addition, under the Indira Awas Yojna.

The State Government also tied up with the State bank of India for providing loans to the beneficiaries whose houses have been categorized under G4 and G5. An interest subsidy of 3% on these loans will be provided by the State Government to the Bank. Therefore the beneficiaries will pay 3% less interest.

Besides the above, HUDCO and BMTPC provided grants and machinery for establishment of the Building Centers, HUDCO provided grants for construction of demonstration units and rehabilitation of 2 model villages and a basti. A grant of Rs. 20 million was provided by CAPART for construction of shelters in the area, first for temporary use of the displaced persons, and then permanently to be used by the community for various purposes.

7.6. CONCLUDING REMARKS

In the aftermath of an earthquake disaster, there is always a great opportunity for upgrading the technology of earthquake resistant construction, creating, awareness amongst the people, training skilled manpower who would continue to construct safer buildings in the area and thereby raising the safety as well as quality of life. This naturally calls for well thought out rehabilitation plan and its implementation. It is hoped that with the various initiatives taken by the State Government as well as other Central Government Organisations, the Chamoli earthquake affected area will achieve the desired safer housing as well as community buildings.

CHAPTER 8. CONCLUSIONS

8.1. GENERAL

The following general conclusions can be made based on our field study of affects of the Chamoli earthquake:

1. The earthquake of 29th March produced catastrophic seismic damage in Garhwal area, and some localized damage in far western middle hills of Nepal, more than 150 km east of epicenter. As discussed earlier, from damage analysis it seems intensity of shaking was moderate.

2. The maximum intensity assigned to Chamoli earthquake is VIII- on the MSK scale, which caused the loss of about 100 human lives and rendered 1,00,000 people homeless. Severe damage were concentrated in an elliptical area (50x20 km), particularly near the apex of the major axis. The elongation and orientation of the isoseismal line for intensity VII reveals rupture may have occurred on a low angle fault in WSW-ENE direction. It has also been concluded on the basis of damage survey that the strong lateral heterogeneity and topography of the area have played major role in the damage.

3. Analysis of strong motion records indicate that the ground motion attenuated very rapidly which can be attributed to the presence of highly fissured rocks. This observation is consistent with the observed intensity of shaking. Also motions in the epicentral region are relatively rich in low frequencies indicating a deep focus event. The maximum PGA value of 0.359g was recorded at Gopeshwar the nearest station from the epicenter at a distance of about 10 km.

4. Most of residential units in the affected area relied on load bearing masonry walls for seismic resistance. Much of the damage could be attributed to ageing, inferior constructions materials, inadequate support of the roof and roof trusses, poor wall-to-wall connections, poor detailing work, weak in-plane wall due to large openings, out-of-plane instability of walls, lack of integrity or robustness and asymmetric floor plans. The extent of damage would have been drastically reduced had modern earthquake-resistant design procedures and construction practices been followed.

5. The basic cause behind the damage is weak building stock i.e. because of weak construction material as well as poor technology. The basic construction material can not be changed significantly in prevailing economy and accessibility of area in both Indian and Nepalese side. The only improvement can be made in use of material and construction technology.

6. More than 98% of buildings are owner-built in study area. Craftsmen basically control the building construction industry. So the building stock improvement is only possible through this channel.

7. Even the government buildings, which involve formal sector, lack the earthquake resistance features in both Nepalese and Indian sides. As it seems, this aspect is even not understood by members of formal sector.

8.2. BENEFITS OF THE STUDY AND LESSONS LEARNED

It was the first opportunity for most of the Nepalese team members to actually see the damage and effects caused by earthquakes in the field. The study allowed hands on information on the damage pattern of different types of buildings, behaviour of different types of construction, materials and technology, their relative merits and demerits. This knowledge would be of great value in the Nepalese context. The team also learnt of the uncertainties associated with damage of buildings and other structures.

The team also had an opportunity to observe damage patterns related to site effects such as topography, foundation soil, directional effects etc., though it couldn't be generalised.

The team learnt different aspects of damage assessment methodology, which could be replicated in Nepal.

The team had good opportunity to see how the crisis was managed, how immediate rescue and relief was affected and how the long term rehabilitation was planned with measures to mitigate the effect of future disaster.

The team surveyed some school buildings also but the damage pattern was not indicative. The damage pattern was very similar to that of other buildings made of similar materials. It seems, in stone buildings made in mud with flexible floor and roof, the mode and intensity of damage is basically governed by the walling material.

One of the purposes of this visit was to verify the Vulnerability Functions developed for School Earthquake Safety Program of the Kathmandu Valley Earthquake Risk Management Project (KVERMP) being implemented by NSET-Nepal was possible to decide on some points in this aspect. However, as the damage was concentrated in stone buildings only, and as there were so many parameters affecting magnitude of the damage, a conclusion couldn't be drawn. The study, nonetheless provided a good database, which, in connection with other earthquakes in the region, could be used in developing Vulnerability Functions in the future.

The field visit provided an opportunity to the team to work with professionals of other nations in this field. It provided a good platform to learn about their activities and latest developments. It also provided an opportunity to discuss on different aspects of common problems. Mutual ideas and concepts were exchanged. The team was able to explore different collaboration possibilities and opportunities. This study also opened many fields of possible collaboration between neighboring countries. This could be a matter taken up in future meetings of South Asian Association of Regional Cooperation (SAARC) as disaster are an annual occurrence in all the SAARC countries.

The Nepalese team learnt the need of understanding, cooperation and co-ordination between different stakeholders in the post disaster management. The importance of raising the awareness of the people about the mitigation measures that could be taken by them to reduce the magnitude of future disaster was also learnt by the team.

8.3. RECOMMENDATIONS

The area hit by earthquake is economically unprivileged and difficult to access. The area is in the highest earthquake hazard zone according to both Nepal and Indian building standards. Following recommendations are made based on socio-economic situation:

- Building stock can be improved by adoption of better building technology. Proposed technology must be understandable to local craftsmen, must not differ much from they are using and use local materials.
- Building Code should be implemented, and proper mechanism should be developed for dissemination of available knowledge to craftsmen, technicians, and people. Only they can convince the house-owners for adoption of better technology.
- Earthquake safety of the building can be improved by improving quality of local building craftsmen. They should be helped to understand weaknesses and limitations of prevailing material and technology.
- On-job-training to craftsmen on earthquake resistant construction can help reduce future earthquake damage. Public shows of shaking table test could help to convince the local craftsmen, people about the better technology.
- Training to technicians, engineers can help improve building stock, at least constructed by formal sector. They can also help to disseminate available technology to the area.

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ANNEXURE 1:DEFINITION OF DAMAGE GRADE

Damage Category	**Extent of Damage in General**	
G0	No damage	No damage
G1	Slight non-structural damage	Thin cracks in plaster, falling of plaster bits in limited parts
G2	Slight structural damage	Small cracks in wall, falling of plaster in large bits over large areas, damage to non-structural parts like chimney, projecting cornices, etc. The load carrying capacity of the structure is not reduced appreciably.
G3	Moderate structural damage	Large and deep cracks in walls wide spread cracking of walls, columns, piers, and tilting or falling of chimneys. The load carrying capacity of structure is partially reduced.
G4	Severe structural damage	Gaps occur in walls; inner or outer walls collapse; failure of ties to separate buildings. Approximately 50% of the main structural elements fail. The building takes a dangerous state.
G5	Collapse	A large part or whole of the building collapse.

ANNEXURE2: LIST OF THE PERSONS CONSULTED DURING THE STUDY

Institutions	Name	Designation
USAID, Kathmandu, Nepal	Mr. Santosh Gyawali	Deputy Executive Officer
	Mr. Ram Gurung	Contracting Officer
Indian Embassy, Kathmandu	Mr. Kulwant Singh	Councilor
BMTPC, Ministry of Urban Development, Government of India, N. Delhi	Mr. T. N. Gupta	Executive Director
TARU Leading Edge, N. Delhi	Mr. Rupal Deshai	Architect
	Mr. Aromar Revi	
University of Roorkee, Roorkee, India	Prof. Navin C. Nigam	Vice Chancellor
	Prof. P. K. Pandey	Pro-Vice Chancellor
Department of Earthquake Engineering, University of Roorkee, Roorkee, India	Dr. A. S. Arya	Emeritus Professor
	Dr. B. C. Mathur	Professor
	Dr. Susanta Basu	Professor
	Dr. Ashok Kumar	Associate Professor
	Dr. J. Das	Scientist
Housing and Urban Development Corporation (HUDCO), N. Delhi, India	Mr. Santosh K. Taneja	Chief, Bldg. Mat. Tech.
RUDO South Asia/USAID, N. Delhi, India	Mr. James I. Stein	Director
	Mr. A. Dasgupta	Program Manager
People in the Earthquake Affected Areas, India	Dr. J. P. Deoshali	Medical Officer, Rudraprayag Hospital
		Local Priest, Chopta
	Dr. V. P. Sharma	Medical Officer, Government AllopathicDispensary, Mandal
	Dr. Uma Kant Panwar	District Magistrate , Garhwal District, Gopeshwor
	Mr. Ratan Singh	Resident,Badhwal, hingharana
	Mr. Makar Singh Tokola,	Resident, Ghinghara
	Mr. Mathwar Singh Rana,	Resident, Dewaldhar
	Mr. Sudarhhan S. Rana	Resident, Dewaldhar

	Mr. Chandra S. Rawat,	Resident, Kansil
	Mr. B. S. Rawat	School Teacher, Augustmuni
People in the Earthquake Affected Areas, Nepal	Mr. Baman P. Neupane	Chief District Officer (CDO), Kailali district
	Mr. Sthaneshwor Devkota	(CDO), Kanchanpur district
	Mr. Gita P. Khanal	(CDO), Dandeldhura district
	Mr. Bhola P. Siwakoti	(CDO), Baitadi district
	Mr. Mohan P. Acharya,	(CDO), Darchula district
	Mr. Rajendra Dev Pandey,	Asst. (CDO), Baitadi district
	Mr. Bhim Bahadur Shahi,	Police Inspector, Baitadi
	Mr. Saraph S. Thagunna	Resident, Baitadi
	Mr. Min Bahadur Thapa	Major, Baitadi.
	Mr. Juddha Bahadur Singh Thakuri	Sub-inspector, Ilaka Police Station, Melauli, Baitadi.
	Mr. Birendra Bahadur Chand	Resident, Melauli.
	Mr. Tika Datta Badu	Resident, Surkal, Durgasthan, Baitadi.
	Mr. Hari Datta Bag	Resident, Salena, Baitadi.
	Mr. Khagda Bahadur Chand	Resident, Shivnath, Baitadi.
	Mr. Ser Singh Kunwar	Resident, Khalanga, Darchula.
	Mr. Indra Raj Badu	Teacher, Darchula.
	Mr. Sarap Singh Thagunna	Resident, Khalanga, Darchula.
	Mr. Madan Raj Pandey	Teacher, Matela, Bagarkote, Dandeldhura.
	Mr. Mahadev Bhatta	Resident, Matela, Bagarkote, Dandeldhura.
	Mr. Narayan Singh Pandey	Resident, Matela, Bagarkote, Dandeldhura.
	Mr. Gore Sarki	Police Constable, Chipur, Dandeldhura.
	Mr. Surendra Bahadur Bista	EarthquakeVictim, Ratani, Dandeldhura.
	Mr. Bal Dev Awasthi,	Resident, Mahendra Nagar municipality, Kanchanpur.
	Mr. Narad Awasthi	Resident, Mahendra Nagar municipality, Kanchanpur