Seismic Hazard and Mitigation Activities in Nepal - with Emphasis on Kathmandu Valley

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Abstract

Earthquakes are the sudden, dramatic and often highly devastating natural disasters. They only last for seconds to minutes, but are the most powerful natural phenomena and generally affect a large area of a country. In case of a great earthquake, the devastation is widespread and can completely paralyze a country or a region for days to months. Furthermore, it may take many years to recover from the damage to the infrastructure and the economy of a country. The trauma and sufferings of survivors may last for a lifetime. In general, the Asian countries such as, Iran, Afghanistan, China, Pakistan, India, Nepal, Bhutan, Bangladesh, Myanmar, Indonesia, Philippines, Japan and many other countries lie in a very high seismic risk zones belonging mostly to the Alpine-Himalayan or Circum Pacific seismic belts.

The recent devastating earthquakes, around south Asia and outside, such as Southern Qinghai, China (M 6.9, 13 April, 2010) Chile (M 8.8, 27 February, 2010), Haiti (M 7.0, 12 January, 2010), Sichuan Province, China (M 7.9, May 12, 2008), Indonesia (Java, M 6.3, May 27, 2006; Banda Achhe, M 9.3, December 26, 2004 and the consequent tsunami), Pakistan (Quetta, M 6.4, October 29, 2008; Muzaffarabad, M 7.6, October. 8, 2005), Indonesia (M 9.3, December 26, 2004,), India (Gujarat, M 7.9, January 26, 2001; Chamoli, M 6.8, March 29, 1999), Taiwan (Chi-Chi, M 7.8, Sept. 9, 1999), Turkey (Izmit, M. 7.4, August 17, 1999; and Duzce, M. 7.1, 12 November, 1999) and Japan (Kobe, M. 7.2, 17 January, 1995) are the reminders to us to realize how vulnerable we are to earthquakes and how important it is to be better prepared to face the future earthquakes.

Earthquakes cannot be prevented and scientists are far from being able to predict them. However, normally they have quite a good idea of identifying the potentially dangerous areas where earthquake may occur in future. Therefore we must learn to live *with earthquakes and at the same time be prepared in advance towards mitigating earthquake hazards by utilizing all the tools that are available from the recent advances in science and technology and lessons learnt from previous events.*

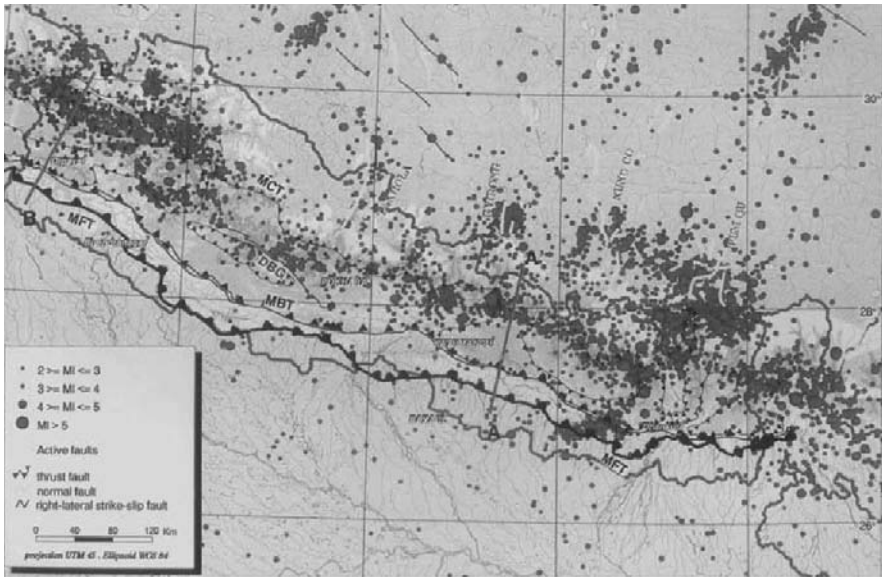
Key Words: Geotectonics, Seismic hazard, Active faults, Kathmandu Valley, Nepal

Himalaya – The Restless Mountain

The Himalaya was formed by the most recent mountain building activity in the Earth's history, and therefore it is also called the youngest mountain on earth. The origin of the Himalaya began around 50 million years ago from the time when the northward moving Indian plate first collided with Asia. During the continued collision process India's front edge was sliced, broken, folded and uplifted to form this youngest and the highest mountain range on our planet. Even at present Indian plate is constantly moving to the north and slips below Tibet by approximately 20 mm annually. This convergence builds up a very large storage of energy in the Himalayan region over a period of time. The energy is stored in the rocks of the Himalaya and adjoining areas. When the accumulated energy exceeds the ultimate strength of the rock, it breaks and slips along a fault (breaks in earth's crust) and suddenly releases the energy. Scientifically, the travel of this energy (in the form of kinetic energy) through the earth in the form of seismic waves is called earthquakes. Most earthquake generating large faults on our earth including the Himalaya region are already known.

Since the mountain building process is still under progress, the Himalaya and surrounding region is seismically one of the most active parts on earth (Fig. 1). The earthquakes occurring in the Himalaya and adjacent regions are often greatly devastating and have killed large number of people in the past. The recent Qinghai and Sichuan earthquakes of China and Pakistan earthquakes were the most recent ones in the series in this region. Some of the largest continental earthquakes on record have been located especially along the Himalayan front. Perhaps earthquakes in the Hindukush-Himalaya-Tibet region and its periphery (China) have killed more people than in any part on earth. This region also includes the most densely populated countries of the world, and nearly one third of Earth's population (over 2 billion) lives here.

Figure 1: Distribution of earthquake epicentres in the Nepal Himalaya and surrounding areas. Circles show epicentre, the size reflects the magnitude. MCT: Main Central Thrust; MBT: Main Boundary Thrust; MFT: Main Frontal Thrust (DMG 1999).



Earthquakes in Nepal

Earthquake records in Nepal since 1253 indicate that Nepal was hit by at least 19 earthquakes (the last major earthquake was that of 1988, Table 1) with various digress of damage. However, the records may not be complete, and the data on loss of life and property may not be very accurate as such data with high reliability are difficult to find. Out of these, the records of the 1833 (magnitude 7.7) and 1934 (magnitude 8.3) earthquakes that occurred at an interval of 100 years give better details and show that these earthquakes were highly disastrous. The effects of these earthquakes were particularly severe in the Kathmandu valley. Nepal established its first seismic station in 1978 under the Department of Mines and Geology, Government of Nepal. Today it has 21 telemetric seismic stations covering the whole country with Kathmandu (central Nepal) and Surkhet (mid western Nepal) as base recording stations. Over the years a great amount of data has been collected which have become very useful for earthquake research in the region (Fig. 1).

Table 1: Some Historic Earthquakes in Nepal
(source: UNDP/UNCHS, 1993, Pandey and Molnar, 1988, Bilham et al., 1995)

Year (A.D.)	Deaths	Damages
1255	Estimated magnitude around 7.7 in Richter scale. One third of the total population of Kathmandu were killed including Abahya Malla , the King of Kathmandu valley	A lot of damages to residential buildings and temples
1260	Many people died, famine after the earthquake	A lot of damages to residential buildings and temples
1408	Many people died	A lot of damages to temples, residential buildings, fissures developed in the ground
1681	Many people died	A lot of damages to residential buildings
1767	No record available on deaths	No record available on damage
1810	Many lives were lost particularly in Bhaktapur	A lot of damages to buildings and temples
1823	No record of deaths	Some damage to houses
1833	Estimated magnitude 7.7, 414 people died in the vicinity of the Kathmandu valley	Nearly 4040 houses destroyed in Kathmandu, Bhaktapur, and Patan in the valley and adjoining Banepa and a total of 18,000 buildings damaged in the whole country.
1834	No good record available	Many buildings collapsed
1837	No good record available	No damage in Nepal recorded but greatly affected Patna and other parts of Bihar, India.
1869	No good record available	No good record available
1897	No good record available	No good record available
1917 (1918?)	No record deaths	No record on damage
1934	Estimated Magnitude 8.3 (epicenter, eastern Nepal). 8,519 people died out of which 4,296 died in Kathmandu valley alone	Over 200,000 buildings and temples etc damaged out of which nearly 81 thousand completely destroyed in the country. Max Intensity X. 55,000 building affected in Kathmandu (12,397 completely destroyed).
1936	No good record available	No good record available
1954	No good record available	No good record available
1966	24 people died	1,300 houses collapsed
1980	Magnitude 6.5 (epicenter far western Nepal). 103 people died	12, 817 buildings completely destroyed, 2,500 houses collapsed
1988	Magnitude 6.5 (epicenter in SE Nepal). 721 people died	66,382 buildings collapsed or seriously damaged.

The Great Central Himalayan Earthquake: An overdue event

Many earth scientists believe that from east to west the entire 2400 km long Himalayan arc can be segmented into different individual parts (approximately 200-400 km) which periodically break and move separately and produce large earthquakes (catastrophic earthquakes). From east to west, the great earthquakes of Assam, India (1950), Shilong, India (1897), Nepal-Bihar (1934), and Kangra, India (1905) were the earthquakes of the last century and earlier produced by the movements in different parts of the Himalaya arc, all with magnitudes around 8.0-8. Although smaller that the historic earthquakes, mentioned above, the recent earthquake of October 8, 2005 in Pakistan, perhaps can be considered as one of them in the series. There were also many intervening medium sized earthquakes that occurred in different sectors of the Himalaya which were of smaller magnitude than the above mentioned earthquakes, but still causing widespread devastation. When a sector of the Himalaya moves and produces earthquakes, it will take some time (from decades to centuries) to repeat the event at the same place.

Today, earth scientists are highly concerned about the lack of occurrence of any great earthquake between Kathmandu in the east and Dehra Dun, India in the west over the past many centuries (Bilham et al, 2001). We may call this gap as the *Central Himalayan Seismic Gap*. It is most likely that any part of this segment is due for a major movement to trigger a large earthquake in the Himalaya. This great impending earthquake with magnitude 8.0 or larger will not only affect the Himalayan region but also the adjacent north Indian plain (the most populous part of India) with devastating effects. Tens of millions of people from the Himalayan region and the north Indian plains may be at risk by this eminent future earthquake. We may term this possible large earthquake as the *Great Central Himalayan Earthquake* (JICA/Ministry of Home Affairs/HMG-Nepal, 2002 named this future earthquake- the Mid Nepal Earthquake if it occurs within Nepal).

Based on the recent study of the aerial photographs and field surveys many active faults have been recognized in the Nepal Himalaya (Fig. 2.) These active faults are the sources of earthquakes. By trenching across an active fault, the past earthquake events and magnitudes produced by that fault can be estimated which can form the basis for earthquake forecasting. Active fault trenching in the Himalaya began only very recently and a few successful trenching in Nepal and India have produced important results. The first successful trenching on an active fault that was carried out in the Himalaya in eastern Nepal at the frontal part of the mountain indicated that the most recent movement on the fault had occurred around 1200 AD producing a large earthquake (Upreti et al., 2000). Similar trenchings in east-central and western Nepal also indicate that two large earthquakes with surface displacement reaching as much as ~20 m have occurred (Lave et al. 2005, Yule et al. 2006). They date approximately 1100 (east-central and eastern Nepal), post ~1450 AD (western Nepal, probably belonging to the known 1505 historic earthquake). These two earthquakes with such large displacements may have produced maga-earthquakes exceeding magnitudes Mw 8.6, that is larger than the 1934 or 1833 earthquakes of Nepal (Fig. 3). Thus, as there have been no large earthquakes in western region since 1505 AD and in the eastern Nepal area since approximately 1100 AD, these areas are now potentially dangerous and may be ready for the next very large earthquakes.

Figure 2. Active fault distribution in Nepal (Upreti et al., 2007). These faults are the sources of earthquake in Nepal.

The 1934 earthquake disaster in Nepal

On January 15, 1934, a big earthquake of magnitude 8.3 struck Nepal and northern Bihar in India, the epicentre lying at around 150 km southeast of Kathmandu. Although Kathmandu Valley had experienced a disastrous earthquake exactly 100 years before in 1833, it was not well prepared for this earthquake. Out of the 8,519 deaths in Nepal over half of the deaths had occurred in the Kathmandu Valley alone. About 20% of the buildings of the valley were destroyed and 40% damaged (Basnet et al. 1998, Fig. 4). The intensity (in Modified Mercalli Intensity Scale-MMI) map of the valley which shows the extent and intensity of damage to structures and other effects is shown in fig. 5. The maximum damage occurred along a belt in the southern part of the valley between Bhaktapur and south of Patan. It took many years to rehabilitate the people in the valley and rebuild the three principal cities of Kathmandu, Bhaktapur and Patan.

Figure 3: Historic earthquakes and their rupture areas in the Himalaya. Larger the area covered bigger is the earthquake. Note that most part of the central Himalayan sector had no large earthquakes (seismic gap) for the last 500 years and more (three very large earthquakes occurred approx. in 1100, 1413 and 1505 AD). (Map after J. Lave).

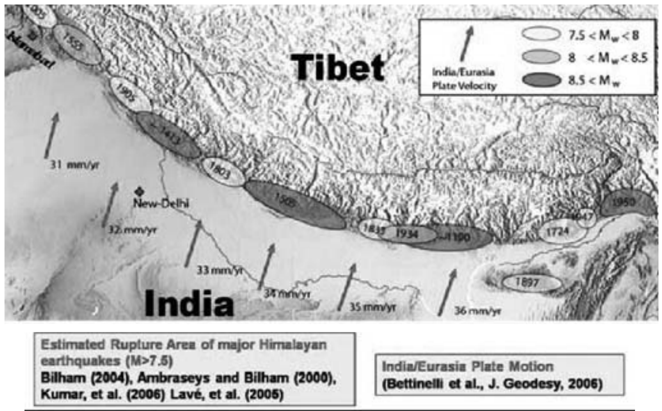
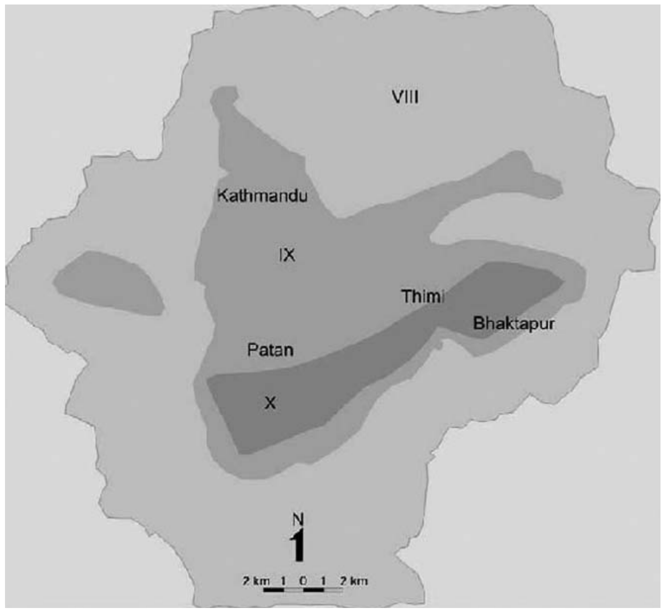


Figure 4: Photo showing destruction by the 1934 earthquakes in the Bhaktapur town, Kathmandu Valley (Photo from Rana, 1935).

Figure 5: 1934 earthquake seismic intensity (MMI) distribution map of the Kathmandu Valley. The Roman letters indicate the Intensity value (Roy et al., 1939, redrawn).



Earthquake Hazard in Kathmandu Valley

Kathmandu - the chaotic capital city of South Asia

After the democratic movement in the country in 1951, Kathmandu, the capital city of Nepal, started growing rapidly out of a small, quiet and beautiful medieval town with a glorious history dating back to many centuries. The city started rapid expansion particularly around 1980s, and had unprecedented growth in the last two decades. Unfortunately, Kathmandu despite being a capital city was allowed to grow to the present size and population (over 3 million, unofficial estimate) without any proper planning. No proper planning for roads, public facilities such as parks and open spaces, sewage system, water supply etc. were done. The whole city grew outward in a chaotic way. Most areas away from the city-core were open farm-land till as late as 1980s. It was not too late for planned development of Kathmandu in the new growth areas. Despite this, the government authorities as well as the concerned municipalities let Kathmandu grow without planning (Fig. 6). The continued unplanned and haphazard urbanization of the Kathmandu Valley has contributed towards its development into a highly vulnerable city particularly to future earthquakes. Most buildings in the valley are vulnerable as most of the buildings are either old and decaying or badly engineered (Figs. 7 and 8). Building code was introduced only very recently but still very poorly implemented

Today, the entire Kathmandu city has only a limited length of winding narrow roads and lanes. Most part of the city is inaccessible to ambulance, firefighting equipment, heavy vehicles, excavators and dumpers. There is also a severe shortage of water supply in the valley. Intertwined electric wires, telephone and TV cables on poles all around the city can be highly dangerous and may cause fire and other disasters during an earthquake. The search and rescue operation in the valley will be a nightmare after a large earthquake.

Figure 6: A recent aerial view of the Kathmandu City. The open space seen at the centre of the photo is Tundikhel. The Bagmati River is seen on the left side of the photo.

Figure 7: A highly vulnerable residential building in Bhaktapur town. The crack in the house had developed during the 1988 east Nepal Earthquake.

Majority of the buildings in the city are either un-engineered or engineered but poorly constructed. There is no effective system of quality control on building construction from the responsible agencies (Fig. 8). Nearly all the buildings have been constructed at owner's own risk.

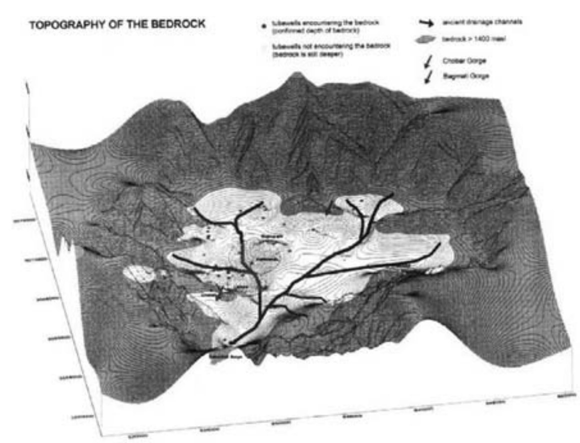
Figure 8: A dangerous building recently built in Kathmandu Valley (Thimi town, east of Kathmandu City).

The quality of most public and government buildings is highly questionable. Therefore, most private and public buildings, hospitals, schools, cinema halls and hotels in Kathmandu are highly vulnerable even to moderate magnitude earthquakes. Thus due to lack of regulation in building constructions and proper planning, Kathmandu has grown into such a chaotic city that recently it has been rated as one of the most vulnerable cities in the world for earthquake disaster.

Weak geologic condition of the Kathmandu Valley

In the past, the Kathmandu Valley was occupied by a large lake, the last part of which may have remained until 10,000 years before present (Sakai et al., 2001). The valley is therefore filled with lake sediments, deltaic and fluvial deposits as thick as 600 m at places (Fig. 9). The sediments are made up of clay, silt, sand and gravel. Recent drillings in these sediments have shown that central part of the Kathmandu Valley is occupied by water saturated very soft sediments up to a depth of about 20 m which may liquefy during an earthquake (Sakai et al., 2001). Buildings and other infrastructures built on such soft and thick soil layers are very vulnerable to the forces of earthquakes as compared to the structures built on rocks or on thinner layers of soil. During an earthquake due to this large thickness of soil layer buildings in the Kathmandu Valley will be shaken very strongly than the buildings in the surrounding hills.

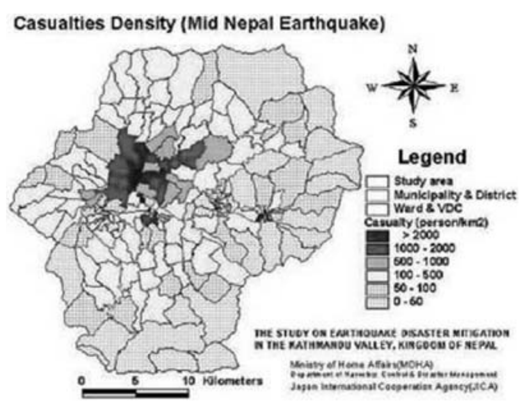
Figure 9: Topography of the Kathmandu Valley. The white portion marks the lake deposit. The thickness of sediment reaches over 600 m at some places (Department of Mines and Geology (DMG), 2000).



Earthquake Scenario

The very weak geological condition of the valley as well as the presence of a large number of old and fragile buildings and poorly constructed new RCC buildings have made the the Kathmandu Valley highly earthquake vulnerable. Kathmandu will be very severely damaged if an earthquake similar to 1934 (Nepal-Bihar earthquake with Magnitude 8.3), occurs. There is an estimate on a variety of effects of a large earthquake (M 8.0 class) that may hit Kathmandu sometime in the future. Based on some preliminary studies, Kathmandu Valley Earthquake Risk Management Project has estimated that during such an earthquake there may be approximately 40,000 deaths, 95,000 injuries and 600,000 or more rendered homeless in the valley (Dixit et al., 1999). A conservative estimate shows that 60-70 % of buildings in the valley will be heavily damaged. Residential buildings are the most vulnerable structures. The JICA/Ministry of Home Affairs/Nepal study (2002) has also provided nearly similar scenario. They have also mapped the probable of density of casualties in the valley (Fig. 10). They have also prepared maps showing probable distributions of seismic intensities, liquefaction of ground, bridge collapse, heavily damaged buildings, and variation of densities of death in the valley in case of a future large earthquake (their Mid Nepal Earthquake). This estimate of casualties may go much higher as the valley population in the last ten years has greatly increased. The casualties also depend upon the timing and duration of shaking by an earthquake. The recent Haiti earthquake of 12 Jan, 2010 with an epicentre near Port-au-Prince, caused over 230,000 deaths, 300,000 injuries and one million homeless. Given the many similarities between Kathmandu and Port-au-Prince, the above damage estimates for Kathmandu is perhaps too conservative.

Figure 10: The estimate of density of casualties in the Kathmandu Valley due to the Mid Nepal earthquake (JICA/Ministry of Home Affairs/Nepal (2002). It is over 2,000 persons per sq km at the centre of the city



The impending big earthquake in Kathmandu Valley may bring an unprecedented disaster. The aftermath of the disaster will be extremely devastating and highly difficult to cope with. The search and rescue operation will be greatly hampered and painfully slow as there are no adequate equipment in the valley such as metal cutters, excavators, cranes, dumpers, and other necessary rescue equipment. Trained rescue personnel, and first aid workers are highly inadequate. The core parts of the three cities (Kathmandu, Patan and Bhaktapur) which are most densely populated with very old buildings and narrow lanes may become practically inaccessible, perhaps for days after disasters, for search and rescue operation. Road access to the valley from outside world will be cut off for weeks to months due to landslide blockage and bridge collapses. The recent Pakistan earthquake provides us the example how earthquake induced landslides can severely affects accessibility in a mountainous terrain. Nepal has a great deal to learn from the Pakistan and Haiti earthquakes.

The airport in the valley may or may not be operative at the beginning. All search and rescue equipment and relief materials have to be transported by air. The airport remains the most critical infrastructure during the operation. There will be severe problem of water supply and sanitary problem. There will be great scarcity of fuel for cooking and firewood to burn dead bodies (culturally, majority of the people in the valley burn dead bodies). Distribution of relief material within the Valley will be most difficult, as many bridges may collapse and roads will be damaged. If the earthquake hits the Kathmandu Valley during the mid-monsoon or mid-winter period, the situation will be even worst due to shelter problem, spread of diseases or cold. Large open space for making camps are highly limited. During such a large natural disaster in a capital city where most decision makers themselves may become victims, the management of search, rescue and relief operations as well as maintenance of law and order is highly likely to collapse at least at the beginning. A large part of the affected people from the surrounding towns and villages out of the valley will flood into Kathmandu in search of medical care, food and shelter making the management even more difficult.

Preparedness- The only Option

It may be emphasized here that the presentation of the above scenario is not to make people panic but to provide a probable scenario and useful information, and make them realize that earthquakes are inevitable in Nepal. People need to understand that it is a natural phenomenon that occurs time to time in the country without warning and cannot be avoided. One should remember that in recent history, Kathmandu was almost completely destroyed in two great earthquakes (1833 and 1934 earthquakes). Also in

1988, the earthquake in eastern Nepal killed 721 and injured over 6,000 people and destroyed and damaged nearly 71,000 buildings all over the region. In 1980 far west Nepal had an earthquake with severe impacts. It is therefore not a question whether a major earthquake will strike Kathmandu (or other parts of Nepal) or not, the question is when it will strike and how well we are prepared for it? As scientists cannot predict the timing of a future earthquake, therefore preparedness is the only option to minimize the impact of an earthquake disaster.

It is often said earthquakes don't kill people; made-made structures kill them. Given the adverse geological condition of the Kathmandu Valley and highly vulnerable existing buildings, and inadequate preparedness, it urgently warrants a serious action for seismic hazard mitigation in the Kathmandu Valley. The population of Kathmandu Valley has increased by over 10 times since the last 1934 earthquake. The search and rescue and relief operation will be extremely complex and will be of a much larger dimension than that of 1934.

Present Seismic Risk Mitigation Activities

Disaster Risk Mitigation is comparatively a new concept in Nepal. Some interests were raised and activities started only after the 1988 eastern Nepal earthquake and 1993 flood disaster of central Nepal. Only very recently people as well as the government and non-government organizations have become somewhat aware of the importance of disaster risk mitigation. The 1990-2000 International Decade for Natural Disaster Reduction (IDNDR) and ISDR also provided some momentum in this direction. During the present interim political state of Nepal the agenda of disaster risk reduction is obviously not on priority. It therefore needs strong persuasion and lobbying for action from all stakeholders. With nation-wide consultation and interaction among all stakeholders a new and comprehensive Act on disaster management was drafted and submitted to the government. It is yet to be enacted by the parliament. Similarly a national policy was drafted and submitted and the government is yet to pass and implement it. These legal documents are necessary for effective disaster management in the country. A National Emergency Plan for an earthquake disaster management also needs to be prepared. In the following paragraphs some of the initiatives on earthquake risk management that are presently being carried out in Nepal are summarized.

1. *Monitoring Seismic activities and crustal deformation:* Department of Mines and Geology (DMG), Government of Nepal maintains 21 seismic stations installed in the country. High quality microseismicity data of Nepal and the surrounding regions are available regularly. The seismic data of the last twenty five years have provided a

good understanding of the seismoteconics of the Nepal Himalaya which is highly useful for seismic hazard mitigation. The recently installed permanent Global Positioning System (GPS) receivers across the country by DMG and the Department of Geology, Tribhuvan University to monitor crustal deformation will provide vital information in future for earthquakes risk mitigation in the country.

2. *Mapping and trenching of active faults:* Active fault research is important in mitigating earthquake risk. Some progress has been made in this direction and a comprehensive survey of active faults have been done. A few trenching in these active faults have been already done and important results are available. Future research should focus on more number of trenching and monitoring of some of the critical active faults in the country.
3. *Implementation of building code:* After a long delay government has enacted a building code for Nepal, and over a dozen of metropolitan and sub-metropolitan cities and municipalities have introduced the code in their respective jurisdictions. However, the implementation part is very weak and even now effective enforcement mechanism does not exist and most new buildings defy the code easily. There is still a lack of commitment and enthusiasm from government and respective municipalities in the strict implementation of the code. Strict implementation of building code is the key element in effective seismic hazard mitigation.
4. *Public Awareness campaign:* It is one of the most important steps towards mitigation of seismic risk. Creating awareness at all levels such as at government, public as well as to the engineering community level is very crucial. Since nearly one decade, great efforts have been made to create public awareness on the possibility of occurrence of earthquakes in Nepal and the need for preparedness. A great deal of credit goes to National Society for Earthquake Technology-Nepal (NSET-Nepal) in creating public awareness. NSET also launched the School Earthquake Safety Program (SESP) in 1999. Nepal Centre for Disaster Management (NCDM), Nepal Red Cross Society, UN Agencies and many other NGOs and INGOs have also contributed in this endeavor. In 1998 Government of Nepal declared 16 January as the National Earthquake Safety Day (ESD) in Nepal. The day is observed every year with many programmes involving a large sector of the society including the government agencies, municipalities, schools children, non-government organizations and other stakeholders. This has greatly helped to increase the public awareness about the seismic hazard in the Kathmandu Valley.
5. *Capacity building:* Enhancing knowledge and skills of masons and construction workers on the earthquake-resistant construction technology is another important

activity that is being carried out in the Kathmandu Valley. NSET-Nepal in collaboration with various municipalities has carried out much such training and over 600 masons and technicians have been trained on earthquake-resistant construction technology.

6. *Community Based Disaster Risk Management Programs (CBDRM):* Several communities of Kathmandu Valley have started this programme in their localities. NSET is providing technical assistance to such communities in implementing earthquake risk management initiatives. Some wards of Kathmandu city have begun the CBDRM efforts by forming Ward Level Disaster Management Committees, recruiting community volunteers and providing training and capacity building opportunities for them. Ward No. 34 and Ward 17 of Kathmandu Metropolitan City have put great efforts in making these initiatives sustainable. Nepal Rec Cross Society and other INGOs have also stared similar activities in various village level communities in different parts of the country. CBDRM has become one of the success stories of Nepal.
7. *Low-cost retrofitting technology for stone masonry buildings:* A large number of mountain people of Nepal live in stone masonry buildings that are highly vulnerable to earthquakes. Prof. J.R. Pokharel, Institute of Engineering, Tribhuvan University and President, Nepal Centre for Disaster Management (NCDM) has developed a cost-effective retrofitting technique for such buildings (Fig.11). Already many residential buildings have been retrofitted in various districts under demonstration programmes. If fund is available, thousands of houses can be retrofitted in the rural areas of Nepal to make the vulnerable population safer from earthquake disasters. Rural Nepal has still retained traditional knowledge of building construction with earthquake resistant features (Fig.12). But gradually such technology is being lost. Efforts should be made to encourage people to use such traditions and popularize them in other parts of the country.

Figure 11: Recently developed retrofitting technique for earthquake disaster mitigation for the stone masonry buildings by Prof. J.R. Pokharel. The bamboo frames from inside and outside of the walls are tied up by gabion wire and finally the frame is covered with mud plaster to protect from weather effects (Photo: Nepal Centre for Disaster Management).

Figure 12: An under-construction stone masonry building at Namche Bazar, Solukhumbu district with earthquake resistant features. Note the wooden separators at different levels of the walls which reduces the effects of earthquake.

Conclusion

Strengthening of legal framework, strict implementation of building code, retrofitting or strengthening of weak buildings, widening of narrow roads, formulation and implementation of effective disaster management plan, training and awareness campaign, improvement of ambulance services, increasing search and rescue capability, and taking every measures towards the seismic risk mitigation will certainly help to minimize the loss of life and property in the Kathmandu valley from a future earthquake. A modest beginning in this direction has been made but a great deal of work is yet to be done and serious challenge lies ahead. As the time is ticking fast, a concerted and serious movement towards seismic risk mitigation must start without delay. The impending earthquakes may strike anytime in near future without warning.

Reference

Basnet, S.S., Cardona, C., Dixit, A.M., Dwelley, L., Nakarmi, M., Pradhanang, S.B., Tucker, B. and Villacis, C., 1998. Kathmandu Valley earthquake risk management project (KVERMP) – an introduction. News Bulletin of Nepal Geological Society, pp. 41-47.

Bilham, R., Gaur, V.K. and Molnar, P., 2001. Himalayan seismic hazard. Science, v. 293, pp. 1442-1444.

Department of Mines and Geology (DMG), 2000. Nepal ma bhukampa ra suraksha ka kehi upaya haru (in Nepali).

Department of Mines and Geology (DMG), 1999. Epicenter Map of Nepal Himalaya.

Dixit, A.M., L. Dwelley, M. Nakarmi, S. Basnet, S.B. Pradhanang, and B. Tucker, 1999. Earthquake Scenario – An effective tool for development planning (a case study- Kathmandu Valley Earthquake Risk Management Project).

JICA/Ministry of Home Affairs/HMG-Nepal, 2002. The study on earthquake disaster mitigation in the Kathmandu Valley, kingdom of Nepal. (5 volumes).

Lavé, J., Yule, D., Sapkota, S., Basant, K., Madden, C., Attal, M. and Pandey M.R., 2005. Evidence for a Great Medieval Earthquake (~A.D. 1100) in Central Himalaya, Nepal. Science, v. 307, pp. 1302-1305.

Pandey, M.R. and Molnar, P, 1988. the distribution of intensity of the bihar-Nepal earthquake of 15 January 1934 and bounds on the extent of the rupture zone. Jour. Nepal Geol. Soc., v. 5(1), pp. 22-44.

Rana, Brahma Samsher J.B. (1935). The earthquake of Nepal (1934) (In Nepali). Published by Brahma Shemsher, 235 pages.

Roy, S.C., Dunn, J.A., Auden, J.A. and Ghosh, A.M.N., 1939, The Bihar-Nepal Earthquake of 1934. Memoirs of the Geological Survey of India, v.73, 391pages.

Sakai, H, Fujii, R., Kuwahara, Y., Upreti, B.N. and Shrestha, S.D., 2001. Core drilling of the basin-fill sediments in the Kathmandu Valley for paleoclimatic study: preliminary results. Jour. Nepal Geol.

Society, v. 25, pp. 9-18.

UN/UNCHS, 1993. Seismic hazard mapping and risk assessment for Nepal. Unpublished Report submitted to His Majesty's government of Nepal, Ministry of Housing and Physical Planning.

Upreti, B.N., Kumahara, Y. and Nakata, T., 2007. Paleoseismological study in the Nepal Himalaya – present status. Proceedings of the Korea-Nepal Joint symposium on slope stability and landslides April, 1, 2007, p. 1-9.

Upreti, B.N., Nakata, T., Kumahara, Y., Yagi, H., Okumura, K., Rockwell, T.K., Virdi, N.S., and Maemoku, H., 2000. The latest active faulting in southeast Nepal. Proceedings of the Hokudan International symposium and School on active faulting, Awaji Island, Hyogo, Japan, 17-26 January, 2000, pp. 533-536.

Yule, D, Lave, J, Sapkota, S.N., Tiwari, D., Kafle, B., Pandey, M.R., Dawson, S., Madden, C., and Attal, M, 2006. Large surface rupture of the Main Frontal Thrust in east-central and western Nepal - Evidence for an unprecedented type of Himalayan earthquake. Proceedings on the International Workshop on Seismology, seismotectonics and seismic hazard in the Himalayan region, Kathmandu, 28-29 November, 2006, pp. 13-14.

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