

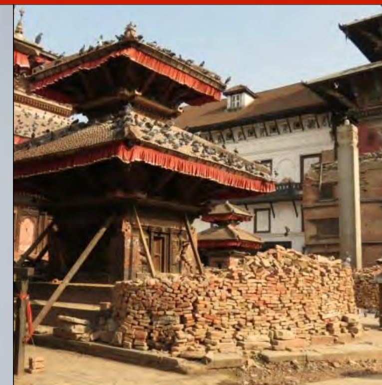

EERI Earthquake Reconnaissance Team Report:

M7.8 Gorkha, Nepal Earthquake on April 25, 2015 and its Aftershocks

Bret Lizundia, Surya Narayan Shrestha, John Bevington, Rachel Davidson, Kishor Jaiswal, Ganesh Kumar Jimee, Hemant Kaushik, Hari Kumar, Jan Kupec, Judy Mitrani-Reiser, Chris Poland, Suraj Shrestha, Courtney Welton-Mitchell, Heidi Tremayne, and Maggie Ortiz

May 2016

A product of the EERI Learning From Earthquakes Program




The Earthquake Engineering Research Institute (EERI) is a nonprofit corporation. The objective of EERI is to reduce earthquake risk by (1) advancing the science and practice of earthquake engineering, (2) improving understanding of the impact of earthquakes on the physical, social, economic, political, and cultural environment, and (3) advocating comprehensive and realistic measures for reducing the harmful effects of earthquakes.

This publication is available in PDF format from http://www.eeri.org.

ISBN: 978-1-932884-67-8

ISBN 978-193288

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PREFACE

A year ago, Nepal suffered a devastating series of major earthquakes, and EERI sent a large, diverse team to study the preparedness steps the country had taken prior to the event, the extent of damage caused by the earthquakes, and the unfolding process of recovery. As co-team leader of the reconnaissance team, it is my great pleasure to announce the release of EERI's reconnaissance report. It is a comprehensive, multidisciplinary, detailed look at the story of the earthquakes and what we can learn about what works and what needs improvements. There are lessons not just for Nepal and the surrounding region, but also for all countries faced with earthquake threats. The report topics include seismology and geotechnical issues; damage to lifelines, buildings, and Nepal's spectacular cultural monuments; building code issues; emergency response and postearthquake safety evaluations; seismic retrofitting; social, psychological, and cultural factors; and EERI's ground breaking efforts in digital documentation of the event. The report is filled with images, data, observations, and recommendations. It is part of a growing collection of information the EERI staff, reconnaissance team, and community have developed on the Nepal earthquakes, including an extensive set of video briefings and a detailed virtual clearinghouse. A dedicated issue of *Earthquake Spectra* is the next step.

Everyone we met in Nepal was extremely gracious in sharing their insights and experience with us during our visit. Unfortunately, over the last year, the country has struggled with political discord and administrative challenges, which have limited the effectiveness and pace of rebuilding. Nonetheless, there is will, there is resolve, and there are many impressive on-going efforts at recovery. Our hearts and our encouragement go out to the people of Nepal, and we dedicate this report to them.

Bret Lizundia
EERI Nepal Earthquake Reconnaissance Team Co-Leader
and
Executive Principal
Rutherford + Chekene

May 15, 2016

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EERI / Bret Lizundia

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1.1 NEPAL BACKGROUND

Nepal is the home to both Mount Everest, the highest mountain in the world at 8,848 m, and tropical plains only 60 m above sea level. It lies in the middle of the Himalayan belt between China to the north and India to the south. With a total land area of 147,181 sq km, Nepal is similar in size to the state of New York and country of Greece (BBC, 2015). Nepal is situated between latitudes of 26°22' to 30°27' north and between longitudes of 80°4' to 88°12' east. Nearly one third of the 2400 km long Himalayan range lies within Nepal, with Nepal occupying the central sector of the Himalayan arc. The east-west length of the country is about 800 km, roughly parallel to the main Himalayan range. The average north-south width is relatively narrow at about 190 km. Nepal has a very diverse environment resulting from its steep topography.

With its ancient culture and the mountainous barrier of the Himalayas, Nepal was closed to the outside world until the 1950s. Nepal adopted a party-less "Panchayat system" from 1960 to 1989, and a multi-party democratic system was established in 1989. Since then, the multi-party parliamentary system was used until a decade-long insurgency eventually led to the abolition of the monarchy in 2008. Drafting of a new constitution was a major political hurdle, and a new constitution was just adopted in September 2015. A new Prime Minister was elected by the parliament in October 2015 in the midst of a severe fuel shortage and political crisis in the aftermath of the Gorkha Earthquake (BBC, 2015).

Before the new constitution, Nepal was divided into five development regions, 14 administrative zones, and 75 districts. Each district was and is headed by a Chief District Officer (CDO) responsible for maintaining law and order and coordinating the work of agencies from various government ministries. By the new constitution, Nepal is divided into 7 provinces. They are defined by Schedule 4 of the new constitution, by grouping together the existing districts (Wikipedia, 2016a). Figure 1-1 shows a map of Nepal with its district boundaries.

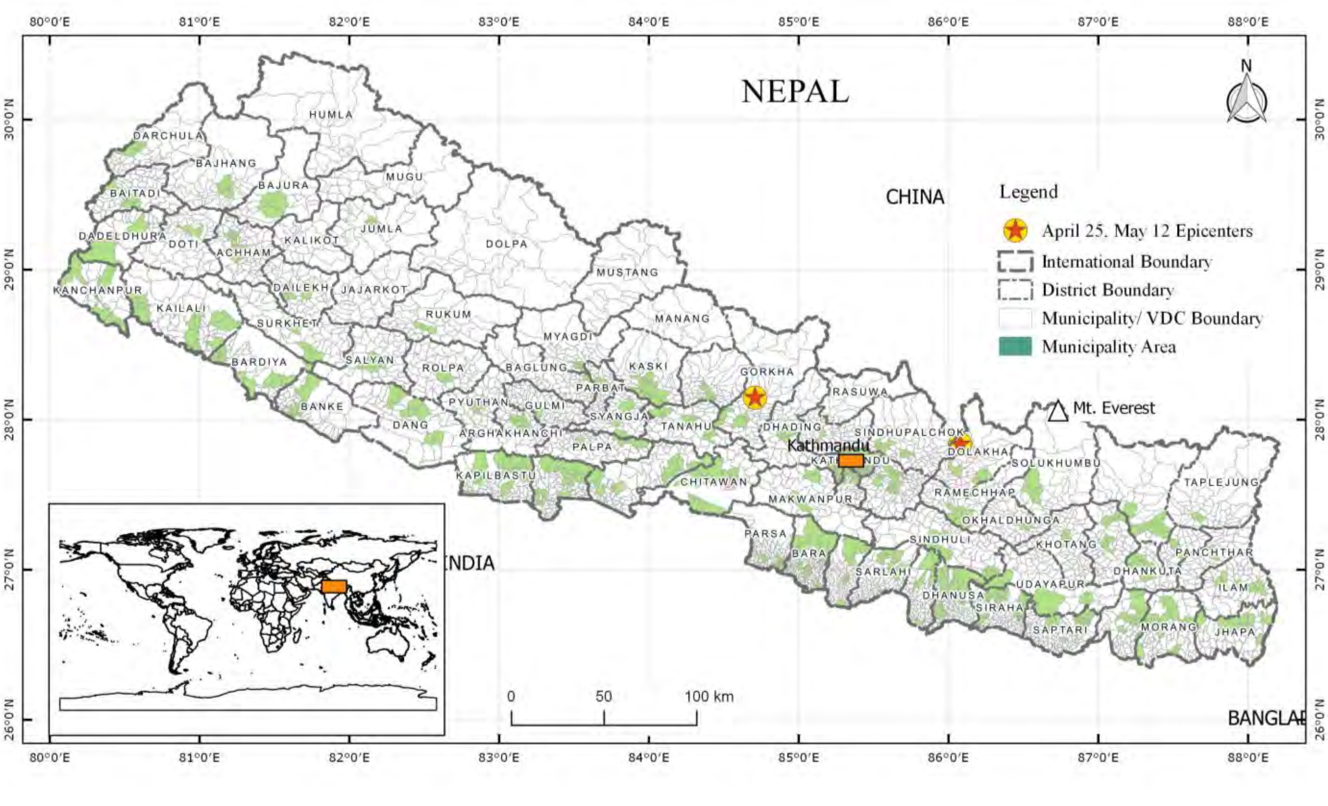

Figure 1-1. Map of Nepal District Boundaries, with an inset map of Nepal's location on a world map (source: NSET, 2015).

A village development committee (VDC) is the lowest administrative unit in Nepal. Each district has several VDCs, similar to municipalities but with greater public-government interaction and administration. There are 3,276 village development committees in Nepal. Each VDC is further divided into several wards depending on the population and geographic situation. The purpose of village development committees is to organize village people structurally at a local level and to create a partnership between the community and the public sector for improved service delivery. A VDC is an autonomous institution and authority for interacting with the people and central government institutions. In doing so, the VDC gives village people an element of control and responsibility in development and ensures proper use and distribution of funds and a greater interaction between government officials, NGOs and agencies (Wikipedia, 2016b).

Nepal had total population of 26.5 million in 2011 with a population growth rate of 1.35% per year. The southern Terai plains and the Kathmandu Valley are the most densely populated areas with population density of more than 500 people per sq km, with national average population density of 180 persons per sq km. Seventeen percent of the population (4.5 million) resides in urban communities, with Kathmandu Metropolitan City being the largest city with a population just over 1 million (CBS, 2012). Figure 1-2 shows a map of the population density.

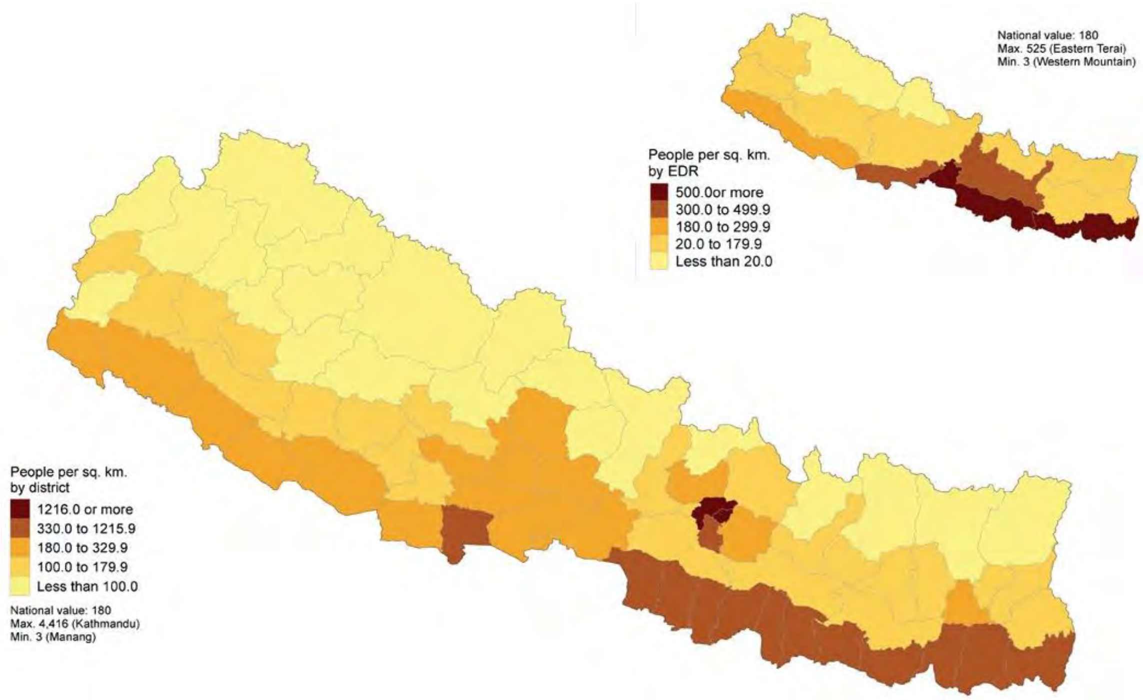

Figure 1-2. Map of Nepal's population density based on data from the 2011 Census (source: CBS, 2012).

There are 123 languages spoken in Nepal per the 2011 Census. Nepali is spoken as the primary language by 45 percent of the population (CBS, 2012).

The average household size in 2011 was 5.1 people. One in every four households reported that at least one member of their household is absent or is living out of the country. Many of these absent household members are located remotely to find paid work and send financial remittances to support their family members in Nepal (CBS, 2012).

The currency of Nepal is the Nepalese Rupee, with an exchange rate of approximately 100 Nepalese Rupees to $1 United States Dollar at the time of the earthquake and immediate response (NPC, 2015). All references to currency in this report use this approximate exchange rate.

1.2 HISTORICAL SEISMICITY AND SEISMIC HAZARD IN NEPAL

The Himalayan region has high seismicity, and Nepal has a long history of damaging earthquakes, as shown in Table 1-1. The map in Figure 1-3 shows the largest historical earthquakes in the region, slightly adapted from Ambraseys and Douglas (2004).

Two major earthquakes occurred in Nepal in the recent past and are worth more detailed discussion. A large earthquake occurred on August 26, 1833 with an epicenter to east of Kathmandu. Historic evidence and records describe extensive damage to the built environment in Kathmandu. A 1995 paper by Bilham mapped approximate Modified Mercali Intensities (MMI) from this earthquake as shown in Figure 1-4. High intensity values of VIII and IX were experienced throughout most of Nepal (Bilham, 1995).

Another major earthquake called the Great Nepal-Bihar Earthquake occurred on January 15, 1934. The epicenter of this M_w8.1 earthquake was located in eastern region, 9.5 km south of Mount Everest (GEER, 2015, Chitrakar and Pandey, 1986). While the epicenter of this earthquake was about 200km east from Kathmandu, the damage was severe in Kathmandu Valley. The earthquake is estimated to have caused around 10,600 fatalities (USGS, 2015a), though other reports estimate fatalities closer to 16,000 in the impacted region (with approximately 8,500 fatalities occurring within the borders of Nepal).

Table 1-1. Major Earthquakes in Nepal Historical Record since 1200 AD (sources: adapted from GEER, 2015, Chitrakar and Pandey, 1986)

Earthquake Year	***Description***
1255 AD (June 7)	This is the oldest known event to severely damage Kathmandu, with an estimated MMI intensity of X (Rana et al., 2007) and a magnitude of M_L7.8. Historical records indicate that many houses and temples in Nepal collapsed, and one-third of the population was killed.
1260 AD	Only five years following the 1255 AD earthquake, this earthquake resulted in collapse of many buildings and temples, and then caused subsequent widespread epidemic and famine.
1408 AD	The earthquake completely destroyed the Rato Matchendranath Temple and caused severe damage and collapse of many other buildings and temples in Kathmandu Valley.
1681 AD	Although limited information is available, heavy loss of lives and collapse and damage of many buildings including temples were noted in Nepal and the Kathmandu Valley.
1767 AD	Reported to cause 21 aftershocks in a 24-hour period. No information is available regarding the loss and damage.
1810 AD	Twenty-one shocks were reported to occur over a month period. The number of casualties was relatively small, but some buildings and temples were destroyed and severely damaged.
1823 AD	Seventeen shocks with moderate magnitudes were felt in the Kathmandu Valley. There was no documented loss of human life or livestock.
1833 AD	Kathmandu Valley was hit by two main shocks in the late summer, one in the afternoon at 6 pm, and the other in the night at 11 pm. Most of buildings, houses, public shelters, and temples collapsed. The Tower of Dharahara was severely damaged. Thimi and Bakhtapur were completely destroyed. Records indicate 18,000 houses collapsed around the country, 4,214 of which were located in the Kathmandu Valley.
1834 AD	Four major shocks were reported during June and July. Although these shocks were not as strong as 1833 shocks, the flooding of the Bagmati River due to excessive rain during the earthquakes caused damage to the bridges.
1934 AD (January 15), Great Nepal-Bihar Earthquake	The strongest earthquake of the 20th century to impact Nepal, this event caused the highest number of casualties ever recorded in Nepal. The earthquake caused major damage throughout a widespread area, where the intensity of the earthquake varied from MMI VII to X. Kathmandu Valley experienced extreme damage, and most of the buildings were destroyed in the three main cities of the valley: Kathmandu, Bakhtapur, and Patan. More than 126,000 houses were severely damaged, and more than 80,000 buildings completely collapsed.
1980 AD	The largest impacts occurred in the far western portion of Nepal from this M_L6.5 earthquake. 125 people lost their lives; 248 were seriously injured. 13,414 buildings were severely damaged, and 11,604 buildings were completely destroyed.
1988 AD (August 21), Udaipur Earthquake	The M6.9 earthquake affected mostly the eastern region of Nepal. It resulted in 721 deaths, 6,553 serious injuries, and damages to more than 65,000 buildings. Total direct loss was reported to be 5 billion rupees.
2011 AD (September 18)	The M6.9 earthquake had an epicenter 272 km east of Kathmandu and caused widespread damage in the Nepal. The earthquake resulted in 3 fatalities, 164 injuries, collapse of more than 6,000 houses, and damage to more than 14,000 houses. (CUEE Report 2011-1)

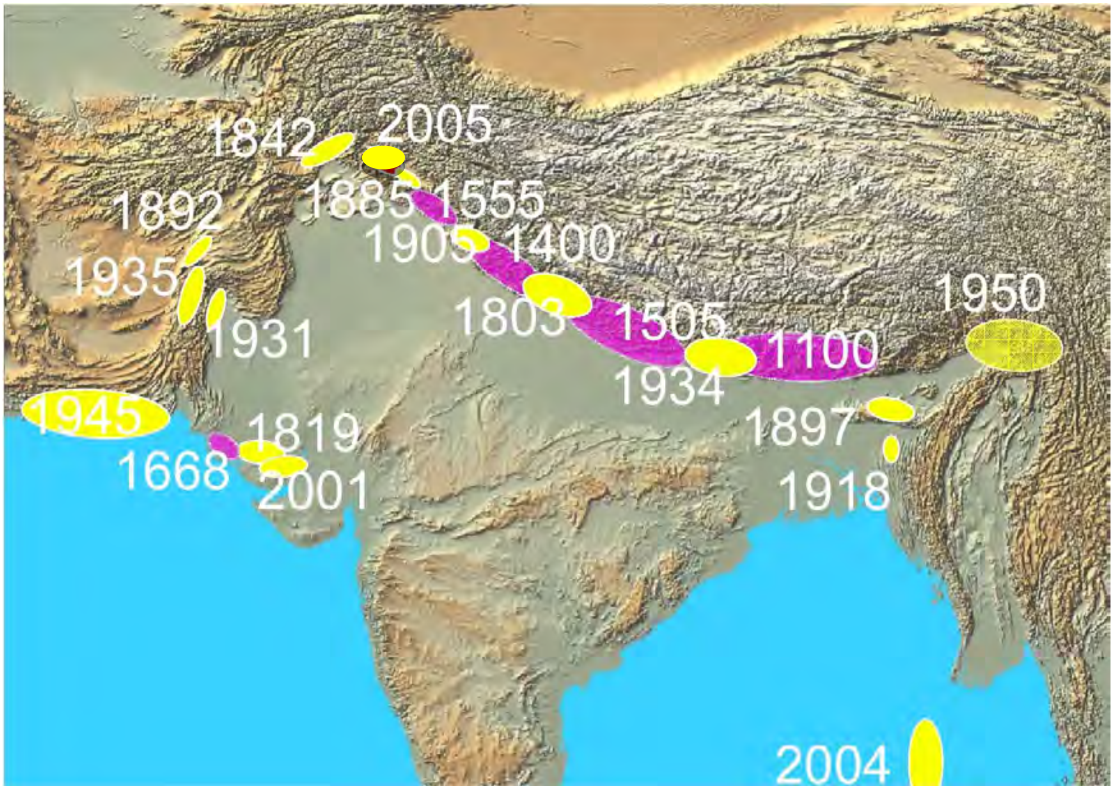

Figure 1-3. Map of historical earthquakes in Nepal and surrounding region with pink areas representing older earthquakes and yellow areas represent relatively recent earthquakes (adapted from Ambraseys and Douglas, 2004).

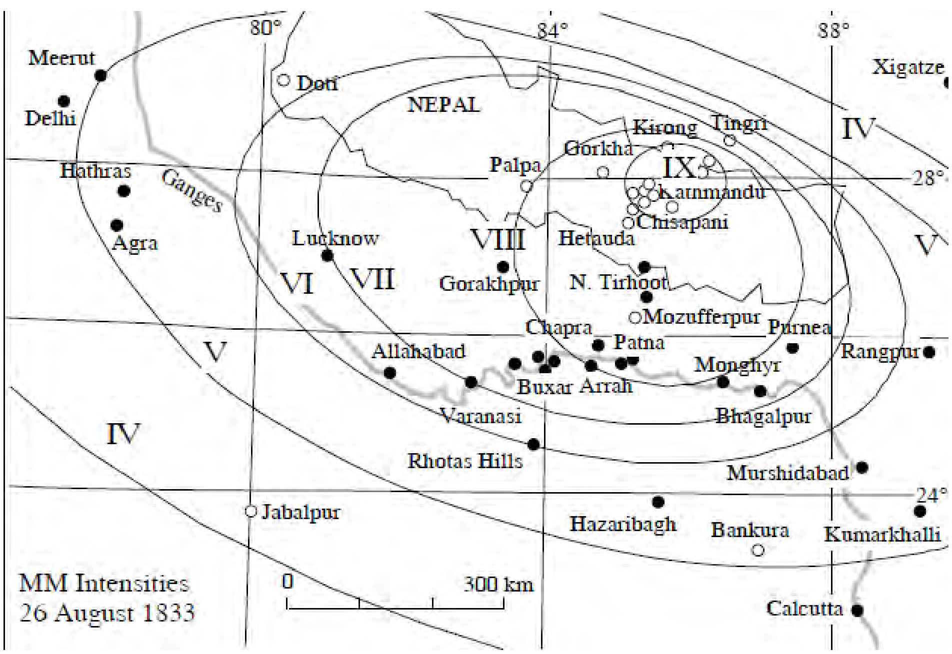

Figure 1-4. Map of Estimated MMI Intensities from the August 26, 1833 earthquake in Nepal (source: Bilham, 1995).

Scientific studies on the seismicity of the Nepal Himalaya show that the region has high seismic hazard, especially in terms of possible maximum intensity of ground shaking. Most of Nepal falls in MMI IX or above for a 475 year return period earthquake (exceedance probability of 10% in 50 years), as shown in Figure 1-5 (GSHAP, 1999). According to the Seismic Hazard Assessment and Risk Assessment for Nepal produced by the Nepal National Building Code Development Project in 1994, peak ground acceleration (PGA) values are also high as shown in Figure 1-6 (UNDP/UN-Habitat, 1994).

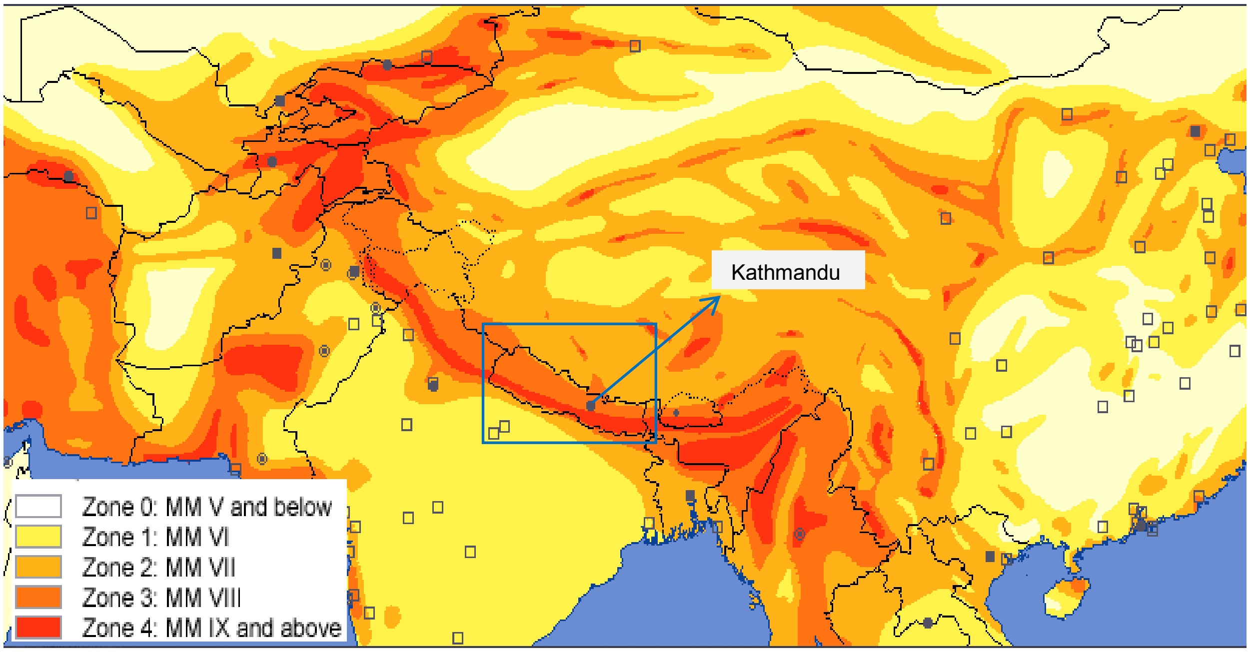

Figure 1-5. Map of the Himalayan region showing the estimated modified Mercalli Intensity (MMI) shaking with a 10% exceedance probability in 50 years (equivalent to return period of 475 years) for stiff soil (corresponding to Vs 760 cm/s) conditions (source: GSHAP, 1999).

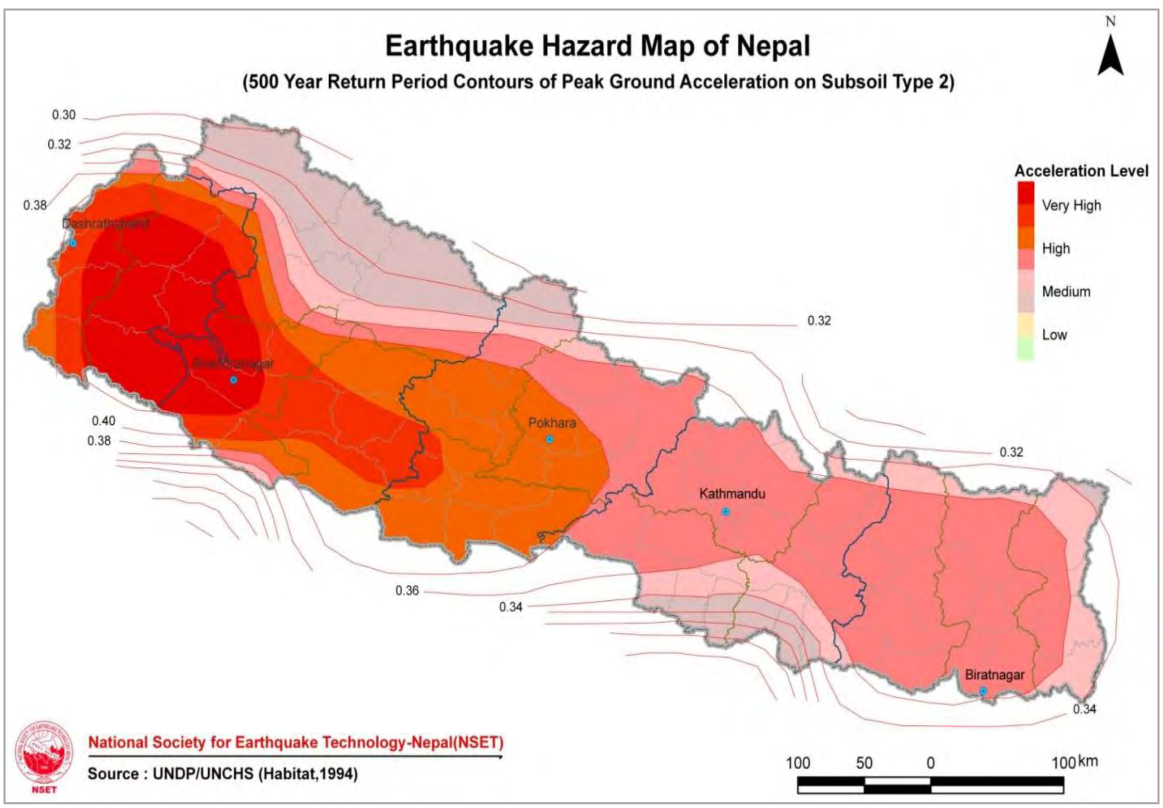

Figure 1-6. Map of Nepal showing PGA contours for 500-year return period earthquakes for average soil, subsoil type 2 (source: UNDP/UN-Habitat, 1994).

1.3 OVERVIEW OF APRIL 25, 2015 EARTHQUAKE AND AFTERSHOCKS

On Saturday April 25, 2015 at 11:56 am local time, the M_w7.8 Gorkha Earthquake occured followed by a strong aftershock sequence (USGS, 2015). Unless otherwise noted, USGS magnitudes will be used for this event. Magnitude readings from other sources sometimes differ. As of March 2016, over 672 aftershocks have been recorded following the April 25 mainshock, including four earthquakes of Mw 6.0 or larger that occurred in the vicinity of the Kathmandu Valley. The May 12, 2015 M_w7.3 aftershock located to the east of the initial epicentral area was the strongest and caused severe damage in Dolakha and Sindhupalchok (also spelled Sindhupalchowk) districts north-northeast of Kathmandu. A map of the main shock and its aftershocks is shown in Figure 1-7.

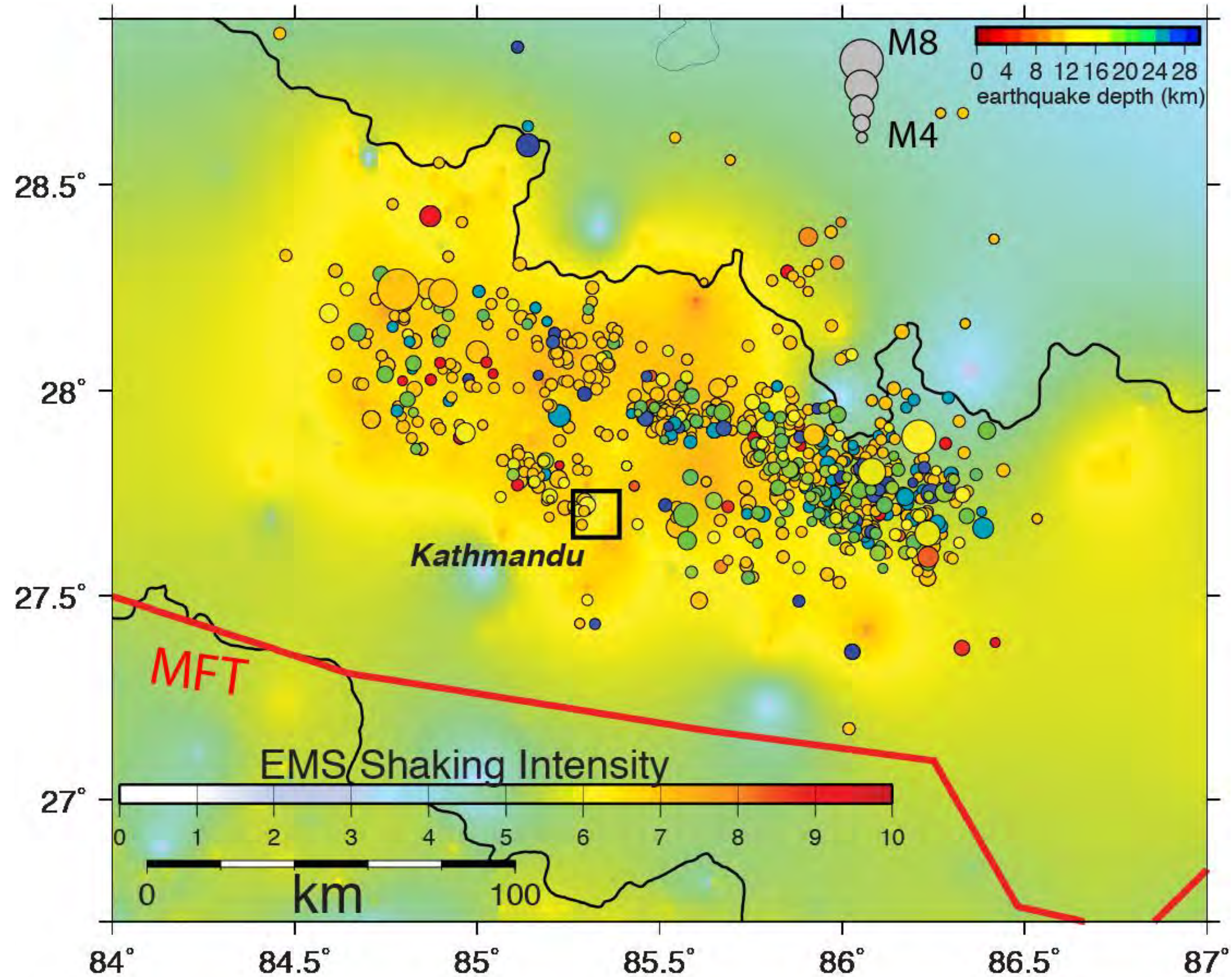

Figure 1-7. Map showing European Macroseismic Scale (EMS) shaking intensity due to the M7.8 Gorkha mainshock (Martin et al., 2015) and a total of 672 aftershocks relocated by McNamara et al. 2016 (Credit: McNamara et al., 2016).

According to the Post Distaster Needs Assessment (PDNA) Report published by the National Planning Commisssion of Nepal in June 2015, there were over 8,790 casualties and 22,300 injuries. It is estimated that the lives of eight million people, almost one-third of the population of Nepal, were impacted by these earthquakes. Thirty-one of the country's 75 districts were affected, out of which 14 were declared 'crisis-hit' for the purpose of prioritizing rescue and relief operations; another 17 neighbouring districts were partially affected as shown in Figure 1-8 (NPC, 2015). Earthquake shaking, casualties, and impacts on infrastructure were also experienced in India, China, and Bangladesh.

The destruction was widespread covering residential and government buildings, heritage sites, schools and health posts, rural roads, bridges, water supply systems, agricultural land, trekking routes, hydropower plants, and sports facilities. Hundreds of historical and cultural monuments at least a century old were either destroyed or extensively damaged. Over half a million houses were destroyed. Rural areas in the central and western regions were particularly devastated and further isolated due to road damage, road obstructions from landslides, and destabilized slopes which also left them more susceptible to flooding and landslides during the subsequent monsoon season. Areas in the high Himalayas and along the Mount Everest route were also impacted by landslides and avalanches triggered by the earthquakes (NPC, 2015).

The PDNA Report states that the disaster highlighted aspects of inequities in Nepali society spanning geography, income, and gender. Poorer rural areas were more adversely affected than towns or cities. Fifty-five percent of casualities were women (UNICGTF, 2015). The report also notes that, if the earthquake had struck at night, and not in the middle of a Saturday, there may have been greater casualties because more people would have been inside vulnerable buildings that suffered damage or collapse (NPC, 2015).

The following chapters of this report describe the impacts in more detail.

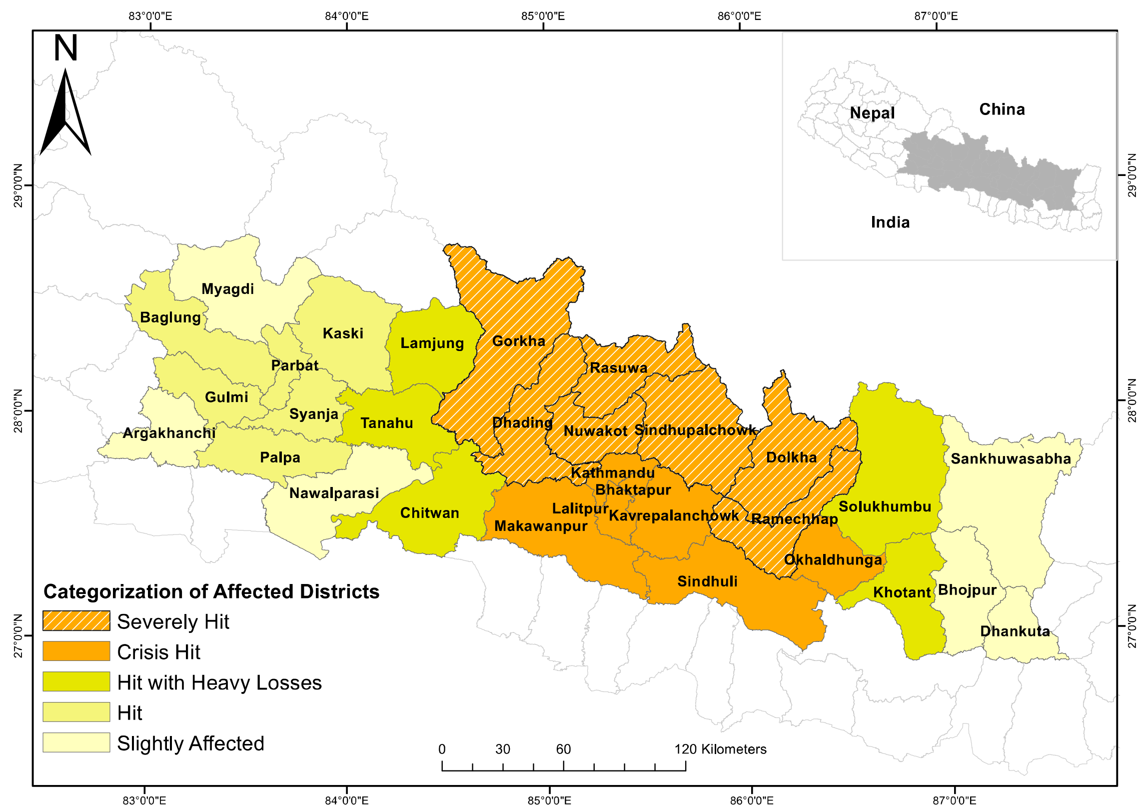

Figure 1-8. Categories of Nepal Districts affected by the earthquake (source: NPC, 2015)

1.4 TEAM MEMBERS

Thirteen volunteers were selected to join the Earthquake Engineering Research Institute (EERI) reconnaissance team for the Gorkha Earthquake, from a list of over 90 members and colleagues who expressed interest to participate. The team traveled to Nepal and conducted field observations in May and June 2015. The team members included:

1. Bret Lizundia, Rutherford + Chekene, San Francisco, USA (Co-Leader)
2. Surya Narayan Shrestha, National Society for Earthquake Technology – Nepal (NSET), Kathmandu, Nepal (Co-Leader)
3. John Bevington, ImageCat Ltd, London, England
4. Rachel Davidson, University of Delaware, Newark, Delaware, USA
5. Kishor Jaiswal, USGS, Golden, Colorado, USA
6. Ganesh Kumar Jimee, NSET, Kathmandu, Nepal
7. Hemant Kaushik, Indian Institute of Technology, Guwahati, India
8. Hari Kumar, GeoHazards International, India
9. Jan Kupec, Aurecon, Christchurch, New Zealand, representing partner organization New Zealand Society of Earthquake Engineering (NZSEE)

10. Judy Mitrani-Reiser, Johns Hopkins University, Maryland, USA
11. Chris Poland, CDP Engineers, Canyon Lake, California, USA
12. Suraj Shrestha, Dharan Sub Metropolitan City, Nepal
13. Courtney Welton-Mitchell, Universities of Colorado and Denver, USA

The team was in close collaboration with other field colleagues including Dr. Thomas Kirsch (Johns Hopkins University) and Rubina Awale (Transcultural Psychosocial Organization, Nepal). Thirteen volunteer virtual team collaborators were also assigned to remotely support team members (as described in Chapter 10).

Deliberations about members of the final team were very thorough and decisions were primarily based upon a careful balance of the following criteria:

1. Knowledge of Nepal and Nepali language(s)
2. Past experience in Nepal conducting scientific studies or risk reduction efforts
3. Disciplinary diversity and balance amongst the team members
4. Availability during the EERI team travel window
5. Reconnaissance and field experience
6. Inclusion of local experts from the impacted region and surrounding countries
7. Expertise in topics particularly relevant to specific Nepal earthquake impacts, including the strategic objectives listed in the next section
8. Ability to liaise with other reconnaissance teams or organizations
9. Possibility of self-funding
10. Active EERI membership status and involvement in EERI activities, including those in direct relationship to the Nepal Earthquake, such as the Housner Fellows and Resilience Observatory

1.5 STRATEGIC OBJECTIVES FOR EERI RECONNAISSANCE TEAM

Before their departure, the reconnaissance team carefully crafted a set of nine strategic objectives to guide the reconnaissance efforts, as shown in Table 1-2. This unique approach was designed to focus team efforts and help prioritize actions. Given the scale of the earthquake and the large size of the reconnaissance team, there are a large number of objectives, but focus areas were defined to clarify specific issues and information sets of interest. Specific objectives and focus areas were assigned to each team member that were consistent with their expertise and interests. These helped in planning and scheduling various reconnaissance activities and mitigated redundant observations.

During the trip, efforts and resources were adjusted to react quickly to logistical constraints, available contacts, serendipitous opportunities, and initial observations, but in general, information was obtained for the majority of the focus areas.

Table 1-2. Strategic Objectives for the 2015 Nepal Earthquake Reconnaissance Team

Objective	***Focus Areas***
1. Evaluate effectiveness of past mitigation and preparedness efforts in a region with well-known very high seismic risk	Hospital retrofits and preparedness
	School retrofits
	Nonstructural hazard mitigation efforts
	Use GHI/NSET previous work
	Emergency shelters and interim housing
2. Investigate lessons from emergency response and building management practices	Aid distribution, airport restrictions/customs limits, temporary shelter effectiveness, emergency plan effectiveness
	Mental health issues
	Search and rescue and postearthquake safety evaluation
	Movement of aftershocks toward metropolitan regions
3. Investigate impacts on lifelines and communications systems including actual and expected restoration times	Interdependencies and work-arounds
	Remote areas vs. Kathmandu Valley
	Coordinate with the ASCE Infrastructure Resilience Division
4. Investigate recovery and resilience related issues	Evaluate framework developed by EERI Resilience Observatory for documenting and measuring resilience
	Investigate impacts and response on remote regions: What features make them more or less resilient?
	Include cultural context issues such as Nepal governance and young men leaving Nepal to find work
	Plan for follow-up visit by resilience team
5. Investigate understanding of damage to regional building types	Organize a compilation of damage photos by building type, by mechanism, and by severity (and potential postearthquake safety tagging recommendation). Attempt to identify average damage to "building clusters," not the isolated extreme cases. Define damage in items of both safety and usability. Use ATC-20 Bhutan (ATC, 2014) as a reference.
	Track damage away from high intensity locations to see where damage starts to die out in different building types to identify intensity level where performance of vulnerable buildings is satisfactory.
	Attempt to correlate damage severity with ground shaking.
6. Evaluate impacts on World Heritage sites	What was pre-earthquake condition and repair/retrofit status?
	What was damaged in past events?
	What happened in 2015 and why?
7. Investigate landslide and avalanche risks	Coordinate with GEER
	How do you tag buildings for landslide risks?
8. Investigate casualty causes	What were the failure modes that led to casualties?
	What were the rates of casualties in different buildings?
	What kinds of injuries were sustained in different buildings?
	What protective actions helped people avoid injuries?
9. Summarize key ground motion features and their significance	25 April 2015 main shock
	12 May 2015 aftershock
	Tectonic environment
	Aftershock distribution
	Strong motion recordings
	Long period motion in Kathmandu Valley
	Comparison of spectra with codes in Nepal and expectations

1.6 TEAM TRAVEL DATES, DURATION, AND TIMELINE

The reconnaissance team members from other countries arrived in Nepal May 30-31 and returned home on June 7-8. Thus, the beginning of the trip was approximately five weeks after the April 25 mainshock and two weeks after the major May 12 aftershock. Initially, EERI had planned to arrive somewhat sooner, but the May 12 aftershock reset the schedule.

The earthquake caused damage over a wide area of central Nepal, well outside of the capital of Kathamandu. Damage was more severe in rural areas. The team felt strongly that it was important to visit both rural and metropolitan area both to observe the areas of greatest damage but also to better understand differences, if any, between damage, response, and recovery in urban and rural areas. Given the large size of the team, smaller groups were established to conduct two to three day visits to three selected areas, plus a number of day trips to areas in the Kathmandu Valley.

The three trips outside the Kathmandu Valley were: 1) Gorkha in the Gorkha District, and Gajuri in Dhading District, 2) Chautara and the Sindhupalchok District northeast of Kathmandu, and 3) the Dolakha District east of Kathmandu. The Gorkha District is where the epicenter of the April 25 mainshock was located; the Sindhupalchok and Dolakha Districts were close to the May 12 aftershocks. Due to the level of damage in these areas, hotel accommodations were not available in the rural areas, and the team camped, often together with those who had lost their homes. Figure 1-9 shows a UN camp in Chautara where the team stayed.

The team was busy during their time in Nepal, usually spread between four to six cars each day, with each car visiting different areas and talking to different individuals and organizations. To give a sense of scale and better identify the locations visited by and some of the activities of the EERI team, see Table 1-3. Not all towns are listed. Figures 1-10 and 1-11 provide maps of locations visited. At the start of the visit, NSET organized a briefing where over 30 representatives from different agencies and organizations in Nepal provided summaries of impacts that they observed or were responsible for addressing. Follow-up interviews were conducted with many of those after the briefing or with others they recommended the team contact. At the end of the visit, the EERI team provided a summary of preliminary observations at NSET's facilities to those who had attended the entry briefing as well as other interested parties.

Figure 1-9. United Nations sponsored camp in Chautara, Nepal on June 2, 2015 (photo: Bret Lizundia).

Table 1-3. Areas Visited by Team Members

Team member	Sunday May 31	Monday June 1	Tuesday June 2	Wednesday June 3	Thursday June 4	Friday June 5	Saturday June 6	Sunday June 7
Bret Lizundia	Kathmandu	Banepa, Dhulikhel, Chautara	Chautara, Herlang-Berlang landslide	Chautara and return to Kathmandu	Araniko Hwy settlement, Bhaktapur, Kathmandu heritage sites	Patan Durbar Square, Sankhu and Nandi-keshwor and their school retrofits	Dhapasi, Gongabu, Swayambhu Temple	Kathmandu, Nepal TV interview
Surya Shrestha	Kathmandu	Kathmandu	Gorkha	Aambu-Khaireni Health Post, Tanahun District, Gajuri Health Post, Dhading District	Kathmandu	Kathmandu	Bhaktapur	Kathmandu, Nepal TV interview
John Bevington	Kathmandu	Gongabu, Balaju, Kathmandu, Dhapasi	Patan, Gongabu, Ramkot, Sitapaila	Charikot, Dolalghat, Kathmandu	Charikot, Jiri	Charikot, Chautara	Bhaktapur	Kathmandu
Rachel Davidson	Kathmandu	Alapot, Kathmandu	Gongabu, Khokana, Ramkot, Sitapaila	Chautara	Kathmandu	Kathmandu	Bhaktapur	--
Kishor Jaiswal	Kathmandu	Gongabu, Kathmandu, Basundhara	Chalnakhel, Ramkot, Budhanilkantha	Dolalghat, Charikot	Charikot, Singati, Syaule Bazar, Bhorle, Suri Dovan	Chautara, Sanga	Bhaktapur	Kathmandu
Ganesh Jimee	Kathmandu	Gongabu, Kathmandu, Basundhara	Chalnakhel, Ramkot, Budhanilkantha	Dolalghat, Charikot	Charikot, Singati, Syaule Bazar, Bhorle, Suri Dovan	Chautara, Sanga	Bhaktapur	Kathmandu
Hemant Kaushik	Kathmandu	Banepa, Dhulikhel, Irkhu, Chautara	Chautara	Dolalghat, Irkhu	Bhaktapur, Kathmandu	Kathmandu, Patan, Nangkhel, Sankhu	Gongabu, Swayambhu, Dhapasi	Kathmandu
Hari Kumar	Kathmandu	Kathmandu	Gorkha	Aambu-Khaireni Health Post, Tanahun District, Gajuri Health Post, Dhading District	Maharajgunj, Kathmandu	Dhapasi Kathmandu	Kathmandu	Kathmandu
Jan Kupec	Kathmandu	Bagmati, Dhulikhel, Kathmandu, Dolalghat, Chautara	Chautara	Charikot, Irkhu, Dolalghat, Khadichaur	Charikot, Singati,	Kathmandu, Patan	Bhaktapur	Kathmandu
Judy Mitrani-Reiser	Kathmandu	Kathmandu	Gorkha	Aambu-Khaireni Health Post, Tanahun District, Gajuri Health Post, Dhading District	Maharajgunj, Kathmandu	Dhapasi Kathmandu	Kathmandu	--
Chris Poland	Kathmandu	Alapot, Kathmandu	Gongabu, Khokana, Ramkot, Sitapaila	Chautara	Kathmandu	Kathmandu	Bhaktapur	Kathmandu
Suraj Shrestha	Kathmandu	Banepa, Dhulikhel, Irkhu, Chautara	Chautara, Herlang-Berlang landslide	Dolalghat, Irkhu	Bhaktapur, Kathmandu	Kathmandu, Patan, Nangkhel, Sankhu	Gongabu, Swayambhu, Dhapasi	Kathmandu
Courtney Welton-Mitchell	Kathmandu	Kathmandu, Banepa, Dhulikhel-Kavre Palanchok, Chautara - Sindupalchok	Chautara-Sindupalchok	Chautara-Sindupalchok, Dhulikhel-Kavre Palanchok	Ramkot, Bhimdunga, Nagarjun Municipality	Bhaktapur	Lalitpur, Kathmandu	Thapathali, Kathmandu

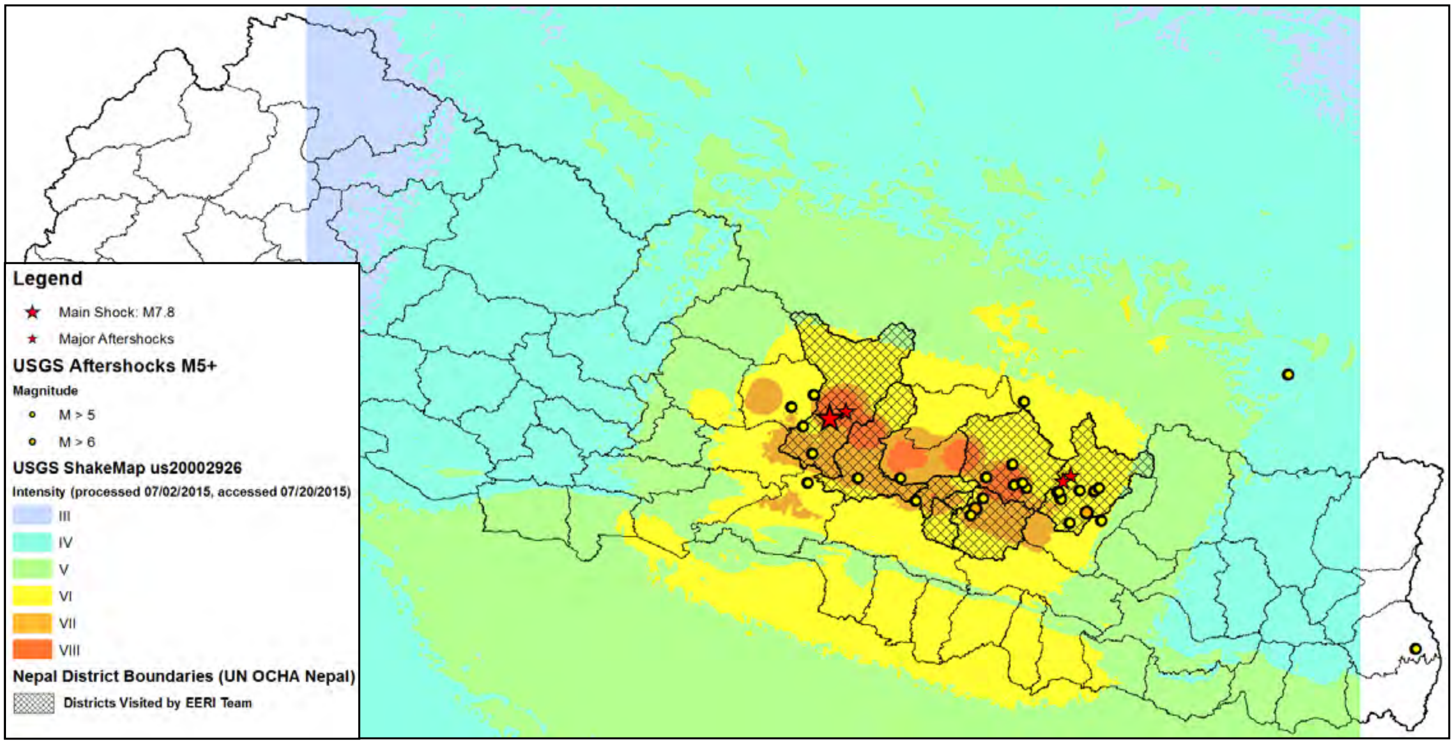

Figure 1-10. Map of Nepal showing districts visited by the EERI Reconnaissance Team with overlays of ground shaking intensity, main shock location, and significant aftershock locations (figures created by EERI with data from USGS, 2015b and 2015c, ESRI, 2015, and UN OCHA, 2015a and 2015b).

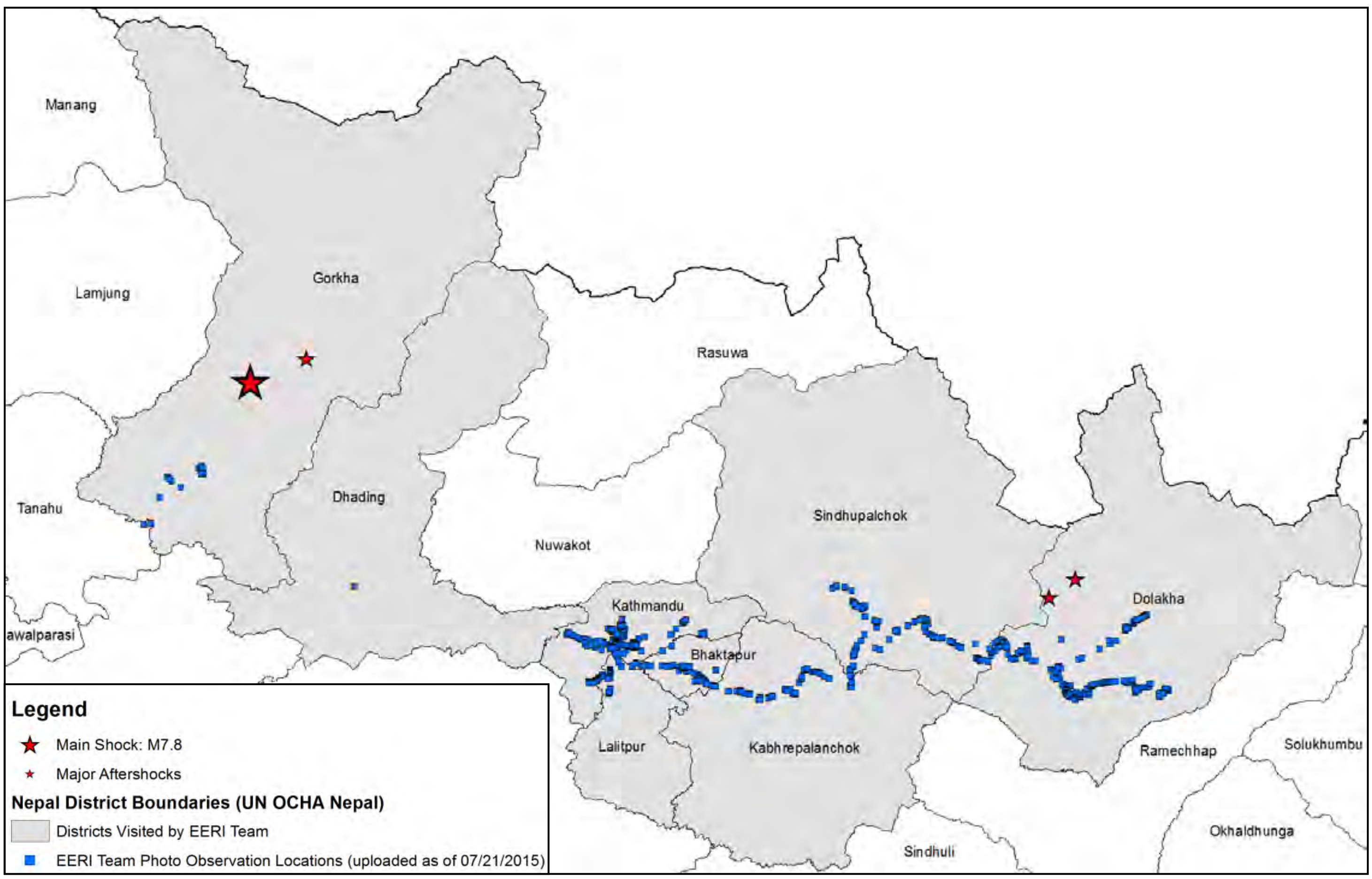

Figure 1-11. Map of districts visited by the EERI Reconnaissance Team in Nepal with overlays of photo observation locations, main shock location, and significant aftershock locations (figures created by EERI with data from EERI, 2015c, USGS, 2015b, and UN OCHA, 2015a and 2015b).

1.7 COORDINATION WITH OTHER TEAMS/ORGANIZATIONS

The success of the EERI Nepal reconnaissance team would not have been possible without the partnership established with the National Society for Earthquake Technology – Nepal (NSET). NSET staff tirelessly coordinated logistics for the team visit and connected the team to many important agencies and colleagues during their visit. Their local knowledge and historical involvement with earthquake risk reduction in Nepal were invaluable, and their collaboration greatly enriched the team's findings.

Numerous agencies, organizations, and individuals also supported the efforts of the EERI team by making time to meet with team members during their visit to Nepal. These groups include, but are not limited to, the following: Bir Hospital, Tribhuvan University Teaching Hospital (TUTH), Kanti Children Hospital, Paropakar Maternity Hospital, Grande Hospital, Ministry of Health and Population, Transcultural Psychosocial Organization (TPO) Nepal, International Organization for Migration (IOM), International Federation of the Red Cross, World Food Programme, Voices of Children, Ministry of Women, Children and Social Welfare, Civil Aviation Authority, Department of Roads, Department of Water Supply and Sewerage (DWSS), Kathmandu Water Supply (KUKL), Nepal Electricity Authority (NEA), Nepal Telecommunications Authority (NTA) and many others. Numerous government offices also met with the team including but not limited to Kathmandu Metropolitan City, Gongabu Ward, Sitapaila Ward, Kageshwori-Manahara Municipality, Sindupalchowk District, and Chautara Municipality.

The team especially thanks the following individuals: Rubina Awale at TPO Nepal, Professor Prem Nath Maskey and Professor Sudarshan Raj Tiwari at Tribhuvan University in Kathmandu, Kishore Jha at the Nepal Engineers' Association (NEA), Homraj Acharya at the Global Fairness Institute, Dr. Youb Raj Paudyal at the Department of Education, Dr. Ramesh Guragain at NSET, Sunil Khadka, Infrastructure Planning Adviser at the Ministry of Health and Population, Hima Shrestha at NSET, Chief District Officer (CDO) and Local Development Officer (LDO) of Dolakha District, Chief Executive Officer of Bhimeswor Municipality, Ram Gopal Shrestha from Bhaktapur Municipality, Rohit Ranjitkar from KV Preservation Trust, Sampat Ghimire and Devendra Bhattarai at Department of Agriculture, Amrit Man Buddhacharya at Swayambhu Management and Conservation Committee, Prabhat Karna, and many others. Special thanks also to the team's guides and interpreters including: Gopi Krishna Basyal, Dev Maharjan, and Hima Shrestha.

EERI staff and reconnaissance team members were regularly in contact with colleagues and members in Nepal as well as collaborating with nearly 30 international organizations also responding to the earthquake and conducting reconnaissance. These organizations included New Zealand Society for Earthquake Engineering (NSZEE), U.S. Geological Survey (USGS), Geotechnical Extreme Events Reconnaissance (GEER), Earthquake Engineering Field Investigation Team (EEFIT) from the United Kingdom, Disaster Research Center at the University of Delaware, Center for Refugee and Disaster Response from Johns Hopkins University, Center for Disaster Management at Karlsruhe Institute of Technology in Germany, Baldridge & Associates Structural Engineering, Canadian Association for Earthquake Engineering (CAEE), National Information Centre of Earthquake Engineering (NICEE) at Indian Institute of Technology (IIT) Kanpur, Architectural Institute of Japan (AIJ), Japan Society of Civil Engineers (JSCE), Australian Earthquake Engineering Society (AEES), and many others.

GEER had an advance team visit the country prior to the EERI team's arrival, plus a larger second team that overlapped with a portion of the EERI team's visit. GEER team members and leaders were extremely helpful in providing advice on logistics and key damage sites. Their support and advice is greatly appreciated.

Finally, many Nepalese community members welcomed the team and graciously shared their experiences during the field observations.

1.8 COMMUNITY CASE STUDIES

Upon their return from the field, the EERI Team selected several communities to document in detail as community case studies. The selected communities include Gorkha, Bhaktapur, Kathmandu Metropolitan City, and Chautara. In papers being prepared for the 16th World Conference on Earthquake Engineering (16WCEE) in January 2017, team members will use multidisciplinary reconnaissance observations about the status and functioning of a variety of community sectors to describe the state of each community at the time of their reconnaissance trip (IAEE, 2016). Key community sectors observed by the team include buildings, housing, livelihoods, physical business infrastructure, social and cultural systems, hospitals and healthcare delivery, schools and educational facilities, and lifelines. The papers will document how the community was organizing for recovery in these sectors (i.e., what were the recovery goals for shelter, livelihoods, and public services), who were the key recovery actors (government, NGO, residents, and businesses), what decisions were being made and how resources were being prioritized to maintain or alter community functions, and why various parts of the urban system survived while others did not.

These communities will be re-visited by other EERI reconnaissance teams visiting Nepal in 2016 that will observe and monitor recovery progress in these case study communities. Based on the initial reconnaissance team baseline information in their 16WCEE papers, it is hoped that follow-up teams can make additional observations about the resilience of each community and document them in future reports or papers.

1.9 ABOUT EERI AND ITS LEARNING FROM EARTHQUAKES PROGRAM

The Earthquake Engineering Research Institute (EERI) is a nonprofit multi-disciplinary technical society of engineers, practicing professionals, and researchers dedicated to reducing earthquake risk. Since its inception in 1949, EERI has conducted postearthquake investigations for the purpose of improving the science and practice of earthquake engineering and earthquake hazard reduction. Formalized as the Learning from Earthquakes (LFE) program in 1973, the mission is to accelerate and increase learning from earthquake-induced disasters that affect the natural, built, social and political environments worldwide. The mission is accomplished through field reconnaissance, data collection and archiving, and dissemination of lessons and opportunities for reducing earthquake losses and increasing community resilience. Volunteer EERI field teams are deployed on trips that aim to document impacts, identify knowledge gaps where further research is most needed, and identify practices that will improve mitigation measures, disaster preparedness, and emergency response for future disasters. The LFE program is led by the LFE Executive Committee and its Chair with additional support from EERI Staff and the EERI Board of Directors.

Special help was provided for this reconnaissance trip to Nepal from various members of LFE and EERI Staff. Ken Elwood, Chair of the LFE Executive Committee, provided critical insight and guidance particularly in the early phases of the reconnaissance trip planning. The members of the LFE Executive Committee also participated in discussions to make critical early decisions about EERI's response to this earthquake. Heidi Tremayne, EERI Program Manager, leads the LFE Program and provided support before, during and after the trip. In close collaboration with Team Co-Leader Bret Lizundia, she also managed the production of the trip final products and deliverables, including this report, the virtual clearinghouse website (EERI, 2015a), and reconnaissance team briefing videos (EERI, 2015b). Maggie Ortiz-Milan, Program Manager, coordinated the data collection and visualization aspects of this reconnaissance trip in collaboration with team member John Bevington. Other members of EERI staff also provided support including Executive Director Jay Berger, Sonya Hollenbeck, Setsu Uzume, and Intern Kelsey Wittels.

1.10 EERI RECONNAISSANCE TEAM VIDEO BRIEFING SERIES FOR NEPAL

Results and findings from this reconnaissance trip were first shared in an online video briefing series that was released to the EERI membership and broader earthquake risk reduction community on July 29th (EERI, 2015b). To ensure that all thirteen team members had the opportunity to share their findings, EERI decided to conduct this briefing in a new way – as a set of pre-recorded online archive of videos instead of the typical live briefings conducted by the LFE program after past earthquakes. This new approach allowed the briefing series to cover more topics than is typically possible in a live briefing and used a format that allowed members from around the world to easily view the videos at a time convenient in their own local time zone. It also created a higher quality archival video set than the video recordings typically produced from live briefings.

The final product was a set of fourteen videos with detailed and well-coordinated slides, for a total duration of nearly 5 hours of technical findings and content. The briefing videos range in duration from 10 to 35 minutes, and can be watched individually or in a series. The final video presented by Bret Lizundia, Team Co-Leader, provided summary of findings by all members, thus providing a quick 30 minute overview of the teams observations. A list of all videos in the series is shown in Table 1-4.

Table 1-4. List of EERI Briefing Videos on the Nepal Reconnaissance Trip

Title	***Presenter(s)***	***Duration*** *(minutes:seconds)*
Introduction to the EERI Learning From Earthquakes Briefing Videos (*Summary of the reconnaissance team objectives, methodology, unique features, and team members*)	Bret Lizundia	13:55
Brief Introduction to Nepal and the Earthquake (*Summary of Nepal's geology, geography, physiographic regions, earthquake hazard, demographics, and earthquake impacts*)	Surya Shrestha	09:33
Seismicity and Ground Motions	Kishor Jaiswal	20:07
Building Performance Part I: Building Type Overview, RC frame with Masonry Infill, and Wood Frame	Hemant Kaushik	14:50
Building Performance Part II: URM Bearing Wall, Postearthquake Safety Evaluation, Barricades/Shoring, School Retrofits	Bret Lizundia	23:53
Health Facility Performance	Judy Mitrani-Reiser and Hari Kumar	29:15
Social, Psychological and Cultural Factors	Courtney Welton-Mitchell	22:11
Geosciences	Jan Kupec	18:19
Emergency Response	Ganesh Kumar Jimee	20:11
Performance of Cultural Heritage Structures	Suraj Shrestha	28:35
Building Codes	John Bevington	23:37
Lifelines	Rachel Davidson	18:04
Resilience and Community Case Studies	Chris Poland	18:43
Summary of Findings	Bret Lizundia	33:18

Feedback from the EERI membership was generally positive for this online video delivery mechanism; thus, this briefing production mechanism is likely to be replicated after future earthquakes.

This report provides additional updates on the team findings since the production of these videos and provides more detail. The outline and chapters follow a similar format as the earlier briefing series.

1.11 ORGANIZATION OF THIS REPORT

This report has been organized into chapters by discipline.

Chapter 2 provides an overview of the geological landscape and features, then describes the seismological aspects of the earthquake and the ground motions induced.

Chapter 3 describes landslides and other geotechnical impacts. This chapter references reports from other field teams where more information can be found on these topics.

Chapter 4 showcases observations about the performance of lifeline systems including electricity, water, telecommunications and transportation.

Chapter 5 describes the performance of the most common building types in Nepal and describes failure patterns.

Chapter 6 outlines the performance of several special use structures like hospitals and schools, and assesses the success of various mitigation programs put in place before the earthquake.

Chapter 7 describes the common types of cultural heritage building types, documents their performance during the earthquake and aftershocks, and makes recommendations for rebuilding of these important cultural monuments.

Chapter 8 outlines the emergency response procedures used after the earthquake, describes their efficacy, and makes recommendations for future emergency response training and planning. It also covers postearthquake safety evaluation, barricades, and shoring for damaged buildings.

Chapter 9 discusses the social, cultural, and psychological impacts of the earthquake on the Nepalese citizens and their communities.

The report concludes with a chapter describing the virtual clearinghouse created by EERI for disseminating and archiving information about the earthquake and from EERI's reconnaissance team. The section describes three new features of this response, including creation of two new volunteer roles of Virtual Team Collaborator and Clearinghouse Curator as well as a new online data map.

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CHAPTER 2

GEOSCIENCES, SEISMOLOGY, AND GROUND MOTIONS

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Acknowledgements:
The authors wish to acknowledge all those who assisted with the journey to and in Nepal and contributed to completion of this report. We had many fruitful and insightful discussions in Nepal with EERI and NSET colleagues. A special acknowledgement is given to Brett Maurer who acted as a virtual collaborator and geo-located a large number of photos on the EERI ArcGIS database. Dr. Jan Kupec wishes to acknowledge the contribution by the New Zealand Society for Earthquake Engineering (NZSEE) who sponsored the Nepal visit, and Aurecon who provide the time needed to complete the visit. Dr. Jaiswal's visit was supported by USAID-USGS sponsored EDAT-I project. Dr. Jaiswal also acknowledges colleagues at USGS, namely Dr. David Wald, Dr. Erol Kalkan, Dr. Gavin Hayes, and Dr. Eric Thomson for their reviews.

2.1 TOPOGRAPHY

The topography of Nepal's southern border with India has altitudes of less than 100 m. Kathmandu Basin is located at about an elevation of 1,800 m (see Figure 2-1). The High Himalayan Mountains feature peaks of more than 8,000 m along the northern border with China on the Tibetan Plateau. In general, Nepal can be divided into five physiographic regions:

- Tethyan/High Himalayas: They range from 4,000 to above 8,000 m. Eight of the highest peaks in the world and the world's deepest gorge, 5,791 m in the Kali Gandaki Valley, are located in this region.
- High Mountains: They feature elevations from 2,200 to 4,000 m. This region consists of phyllite, schists, and quartzite, and the soil is generally shallow and resistant to weathering. The climate is cool and temperate.
- Middle Mountains: Also known as the Mahabharat ranges, the elevation ranges from 1,500 to 2,700 m, and the region is cut in many places by rivers. They are the first great barrier to monsoon clouds, and the highest precipitation occurs on the southern slope of this range.
- Siwalik: Commonly referred to as the Churia Hills, the elevation ranges from 700 to 1,500 m.
- Terai: The northern part of Indo-Gangetic plain. The Terai extends nearly 800 km from east to west and about 30-40 km from north to south. The average elevation is below 750 m and as low as 100 m. Geologically, it consists of alluvial plains and extensive alluvial fans. About 50 percent of the population lives in the fertile Terai region, but less than eight percent of the population lives in the High Mountains and the Himalayas.

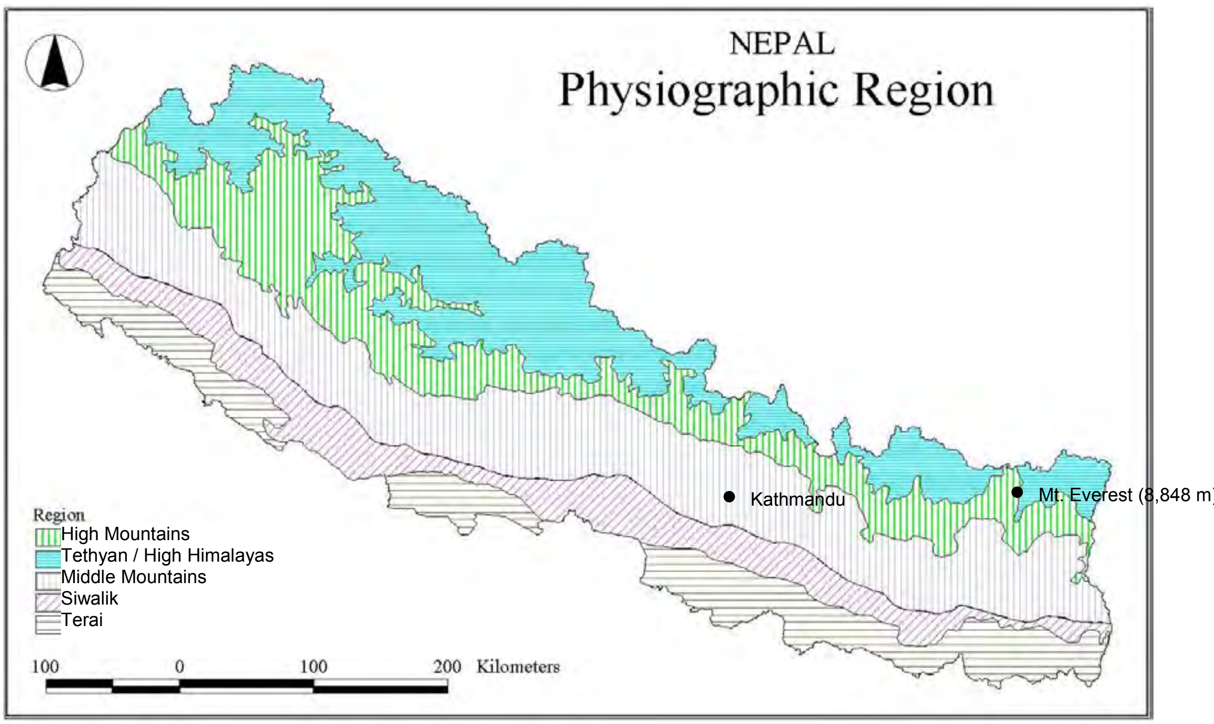

Figure 2-1. Topographical setting and physiographic regions of Nepal (after Survey Department of Nepal, 2011)

2.2 TERRAIN

Rapid uplift of Nepal's terrain due to seismic uplift (described more in Section 2.5), and corresponding rapid riverine erosion, created a very distinct landscape in the Middle Mountains. The terrain is dominated by steeply sloping terraced agricultural land and villages and townships along prominent mountain ridgelines, as shown in Figure 2-2. The area mainly affected by severe seismic shaking from the Gorkha Earthquake and its aftershocks is the Middle Mountain Range.

Figure 2-2. Typical view of terraced landscapes and deep riverine erosion in the Middle Mountain area, photo 27° 41' 56.559'' 86° 3' 32.719' (photo: Jan Kupec)

2.3 GEOLOGY

The geology of Nepal is complex, with subduction of the Indian Subcontinent below the Eurasian Continental Plate forming a collision that uplifted and folded soil and rock layers in a complicated pattern. Detailed geological maps are available on the Nepalese Department of Mines and Geology GIS system (Department of Mines and Geology, 2015).

The lower elevations of Nepal are characterized by outwash soils ranging from clays to coarse gravels. The middle mountains of Nepal are dominated by pebbly sandstones and mudstones, with conglomerates in higher elevations. The higher mountains are predominantly composed of sedimentary and metamorphic rocks including slate, phyllite, schist, quartzite, limestone, and dolomite. The High Himalayas are mainly comprised of heavily metamorphosed coarse grained rocks such as gneisses and igneous rocks such as granites, and the Tibetan Plateau is comprised of shale, limestone, and sandstone sedimentary rocks.

2.4 HYDROLOGY

There are many rivers in Nepal draining from the High Himalayan Mountains towards the lower lying Terai flat lands. Three principal rivers, Koshi, Gandaki, and Karnali, originate from glaciers and snow-fed lakes. They break southward through deep Himalayan gorges and enter low lying basins. As they flow towards India, they become tributaries (as are all Nepal's rivers) of the Ganges River system. High variation in seasonal precipitation by monsoon rainfall creates regular flooding and high riverine flows. Monsoon rainfalls affect land stability in the mountainous regions of Nepal, and land instability and reactivation of landslides and rock falls during the monsoon time is common. Further details on riverine settings and Nepalese hydrology can be obtained from the Department of Hydrology and Meteorology (Department of Hydrology and Meteorology, 2015).

The river system in Nepal is extensively used for hydroelectric power generation and some smaller irrigation schemes. Locations and damage to the hydroelectric infrastructure is described in detail in the GEER report (GEER, 2015).

2.5 TECTONIC SETTING

The Indian and the Eurasian plates are converging at a relative rate of 40-50 mm per year, which results in a net uplift of Himalayan mountain ranges by approximately 18 mm per year (USGS, 2015a), as shown in Figure 2-3. The surface expression of the plate boundary is marked by the foothills of the north-south trending Sulaiman Range in the west, the Indo-Burmese Arc in the east and the east-west trending Himalaya Front in northern India. The seismic activity in the Himalayan region is mainly due to the continental collision of these two plates (northward underthrusting of India beneath Eurasia).

Similar to other parts of the Himalaya, from south to north, Nepal can be also subdivided into the five major tectonic zones that correspond to the physiographic regions discussed in Section 2.1. Each of these zones is characterized by their own lithology, tectonics, structures, and geological history. These tectonic zones are separated from each other by major thrust faults. The southernmost fault, the Main Frontal Thrust (MFT), separates the Sub-Himalayan (Siwalik) Zone from Gangetic Plains. The Main Boundary Thrust (MBT) separates the Lesser Himalayan Zone from Siwalik. The Main Central Thrust (MCT) separates the Higher Himalayan Zone from the Lesser Himalayan Zone. The South Tibetan Detachment System

(STDS) marks the boundary between the Higher Himalayan Zone and the overlying fossiliferous sequence of the Tibetan-Tethys Himalayan Zone. The Indo-Tsangpo Suture Zone is the contact between Indian plate and Tibetan (Eurasian) Plate in terms of plate tectonics. A typical cross section showing the major faults is shown in Figure 2-4.

Any of these fault systems are able to generate strong seismic shaking. A summary of seismic events since the 13th century in Nepal is discussed in Chapter 1, Section 1.2.

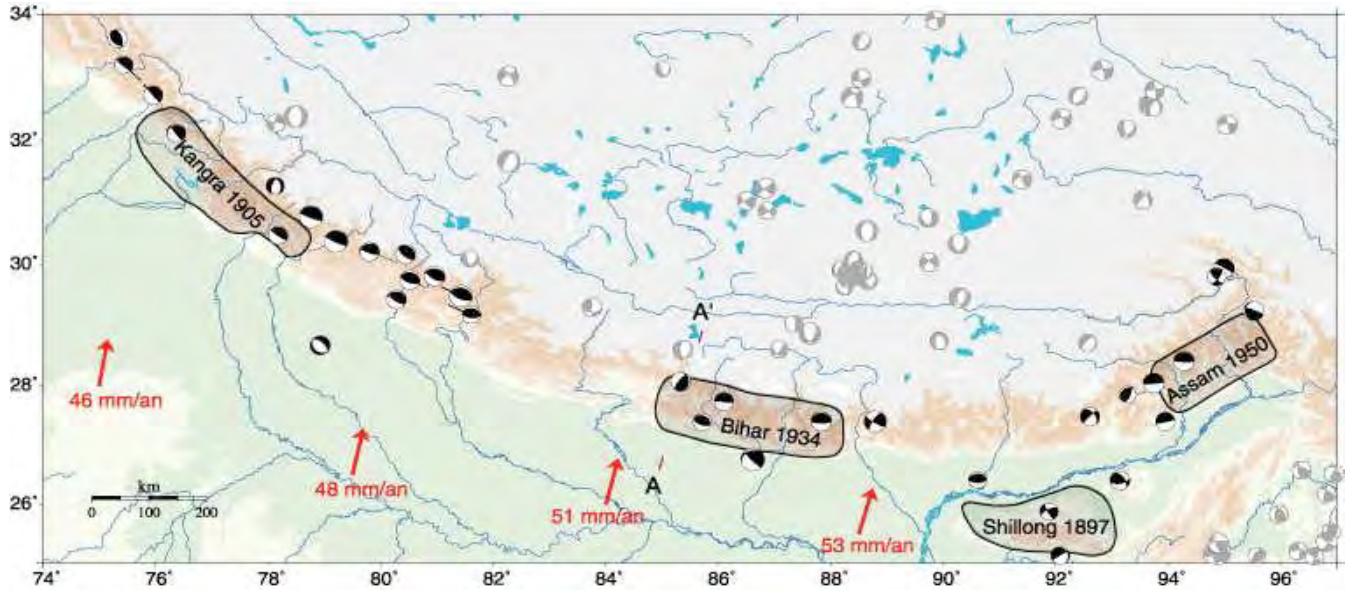

Figure 2-3. Historical seismicity showing major earthquake (Mb >5) along the Himalaya since 1897 and the geodetic strain rates along the Himalayan front. Note that the 2005 M_w7.6 Kashmir earthquake is not labeled in the original diagram because it occurred slightly northwest of the map boundary (source: Avouac et al., 2001).

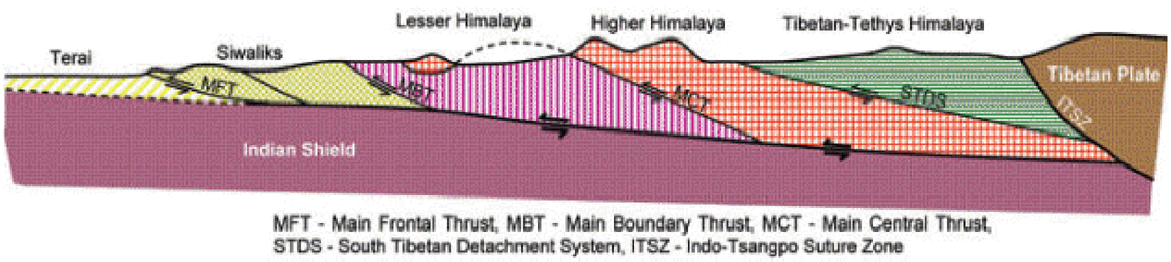

Figure 2-4. Generalized cross section of Nepal (after Dahal, 2006).

2.6 GORKHA EARTHQUAKE SHAKING AND INTENSITY

The April 25, 2015 M_w7.8 earthquake occurred as a result of thrust faulting on or near the main thrust interface along a shallow décollement (gliding plane between two rock masses) along the Main Himalayan Thrust between the subducting India plate and the overriding Eurasia plate to the north (Figure 2-5). The slip distribution reveals a unilateral, eastward-directed rupture with a combined rupture length of ~150 km, peak slip close to 6 m, and up to 5 m of slip in the aftershock (Hayes et al., 2015). The rupture propagated to the east from the epicenter towards the north of Kathmandu.

The earthquake effects were felt differently across Nepal. Strong to severe seismic shaking, often recorded and reported as high frequency high amplitude shaking was reported in the epicentral regions. Whereas in the Kathmandu Basin due to deep lake bed deposits, the city experienced a high amplitude with low frequency shaking. Video footage of pedestrians reacting to the main earthquake shows significant sideways motions are visible over longer periods of time, i.e. most people are able to remain standing but are moved several meters sideways by the ground lurching.

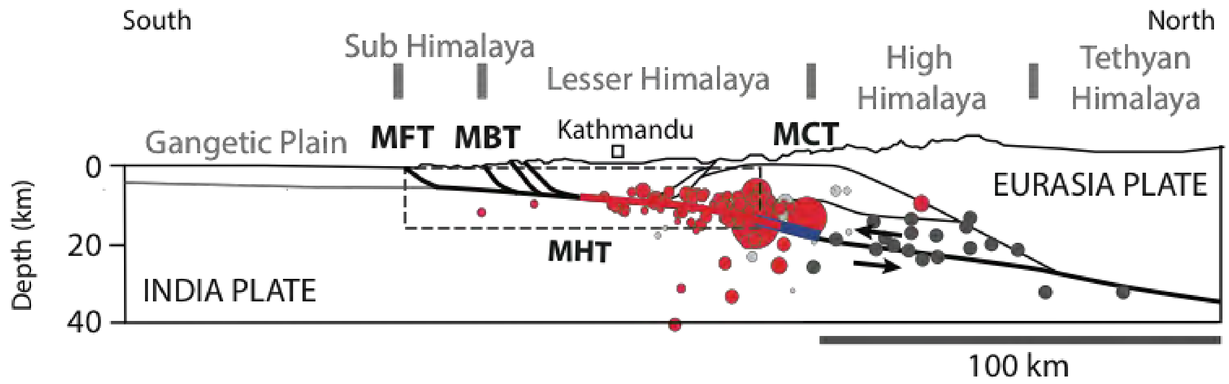

Figure 2-5. Generalized cross section showing the approximate locations of slip during the 25 April and 12 May 2015 ruptures on the Main Himalayan Thrust and approximate aftershock locations of both events. Historical earthquakes are shown in gray and the calibrated aftershock relocations are shown in red. MFT = Main Frontal Thrust, MBT = Main Boundary Thrust, MCT = Main Central Thrust (source: Hayes et al., 2015; cross section generalized after Lave and Avouac, 2000 and Kumar et al., 2010).

2.6.1 Kathmandu Valley Basin Shaking Amplification

The capital of Nepal and largest urban center, Kathmandu, is located within a large sedimentary basin. The former lake bed is relatively level and crossed by several rivers and smaller streams. Kathmandu Valley is surrounded Shivapuri Hill in the north and Phulchauki Hill in the south. The basin is characterized by thick semi-consolidated fluvio-lacustrine quaternary sediments on top of basement rocks (Sakai, 2001). The maximum thickness of sediment layers reaches up to 550 m in the central part of the valley (Figure 2-6).

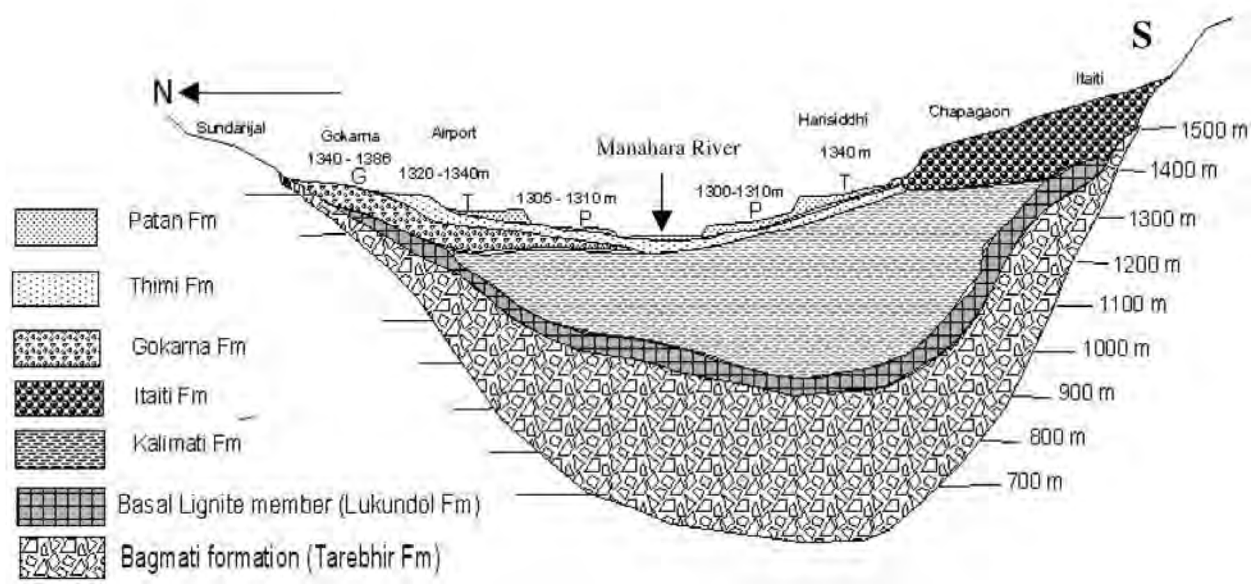

Figure 2-6. Geologic cross section of Kathmandu Valley basin showing depth of sediments and their stratigraphic formation. Sundarjail to Chapagaon is 26 km long. The airport location shown in figure approximates the location of downtown Kathmandu. The vertical scale is exaggerated by several orders of magnitude (source: Sakai, 2001).

The Kathmandu sedimentary basin can amplify ground motions at low to moderate shaking levels due to weak soils with relatively low shear wave velocities from 167 to 297 m/s (Chamalagain and Gautam, 2015) and peak basin response natural frequencies ranging from 0.5 to 8.9 Hz (Paudyal et al., 2012). During the 2015 M7.8 mainshock, there is evidence that the shaking levels were large enough that the soils responded nonlinearly, resulting in deamplification at high frequencies (Rajaure et al., 2015).

2.6.2 Ground Motion Recordings

There were number of strong ground motion stations operational within the Kathmandu Valley at the time of Gorkha Earthquake. However, the data from only one strong motion station (USGS KATNP station, which is a soil site record) was publicly available until 2016. Only recently, Takai et al. (2016) have published the strong ground motion observations from four other stations that were located within the Kathmandu Valley. Similarly, the metadata from another station operated by Department of Mines and Geology (DMG station), was also recently made available.

Table 2-1 summarizes the peak amplitude of ground motion registered at each of the six stations that were located within the Kathmandu Valley basin. The strong motion records from these stations revealed a number of important characteristics about the ground shaking experienced within the Kathmandu Valley basin that are extremely important from future earthquake hazard characterization of this region. Figure 2-7 depicts the rough boundary of the sedimentary basin (shown with white and yellow region) along with the location of strong ground motion stations. Except the KTP station, which was located on the rock site, the other four KATNP, TVU, THM, and PTN stations showed similarities in ground motion characteristics being located on slightly consolidated soil sites (Figures 2-7 and 2-8).

The KTP station situated on a rock site recorded a peak ground acceleration (PGA) of 0.24 g which was highest among all the stations within the Kathmandu Valley. For most soil sites, the PGAs ranged from 0.15 to 0.24 g. The ground accelerations are relatively low for the large magnitude of this earthquake and the proximity of the rupture from the location of these stations. Interestingly, all stations registered relatively high ground velocities, exceeding 100 cm/sec at KATNP station and between 50 to 90 cm/sec at other stations. The peak spectral demand at short periods (0.2 sec), i.e., for one to three story buildings located on soil sites, can be calculated for each site which ranges from 0.25 to 0.3 g, and it exceeded 0.4 g at the rock site.

In general, the two horizontal components of strong motions recorded on soft sedimentary sites showed ground motion amplitudes peaking at longer periods. For example, as shown in Figure 2-9, the KATNP record included strong long period waves (with an approximate period of 4.5 sec, i.e., frequency of ~0.2 Hz) in the east-west direction (which is roughly parallel to the principal axis of the fault plane geometry). Figure 2-9 also shows a much lower spectral acceleration at short periods (< 1 sec) and much higher accelerations at long period range (between 4 to 6 seconds) compared to UBC design levels. The spectral demands generated at such long period portion of the response spectrum are quite unique and of interest to engineering community. However, the vertical component of strong motions at these sites did not show such long-period oscillations (Takai et al 2016).

Galetzka et al. (2015) used GPS and InSAR data to model the source rupture characteristics and concluded that the smooth slip onset and the related large slip-weakening distance provide an explanation of the relatively low amplitude of shaking at frequencies above 1 Hz (since smoother rupture is generally associated with weaker high frequency radiation). An alternative interpretation is that the high-frequency energy was confined to the deeper portion of the fault rupture (Ampuero et al., 2016).

Note that much of the building stock in Kathmandu Valley is composed of low and mid-rise reinforced concrete frames with infill masonry construction (with natural period < 1 sec). These buildings did not experience the peak spectral demands associated with the mainshock records in the 4.5 sec period range. Similarly, the peak ground accelerations and the spectral demands at shorter periods (less than 1 second) were relatively low when compared with standard ground motion prediction models (for example, Boore et al. 2014 as shown later in Section 2.9). The amplification at the long period range could have been caused due to deep basin response from strong shaking, which was further complicated due to the source rupture characteristics. However, such strong amplitude in the longer period range was not witnessed for the KTP station, which was located on a rock site.

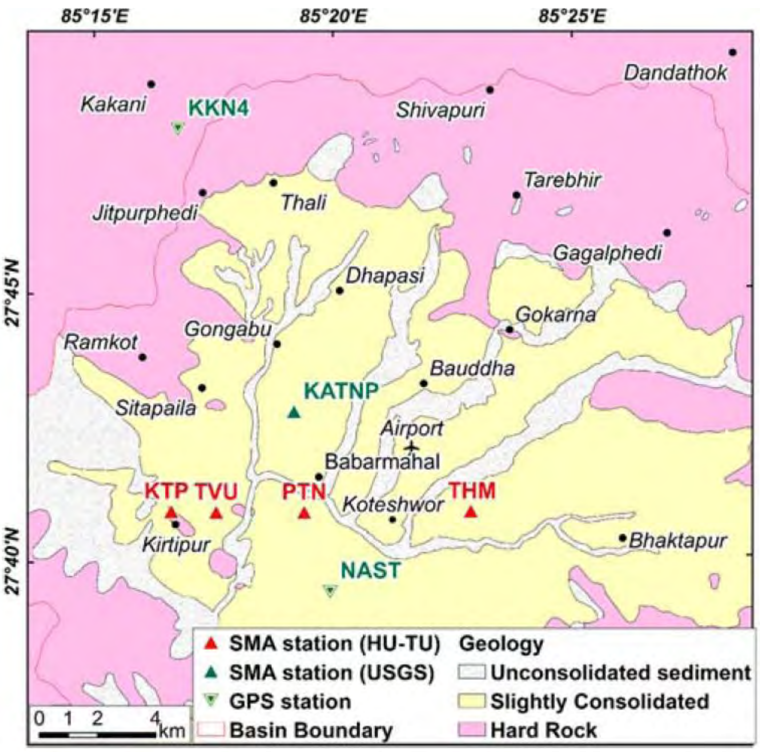

Figure 2-7. Locations of strong ground motion stations by site category within the Kathmandu Valley basin. Except KTP station (which was on a rock site), all the seismic stations shown on the map were located on soil sites (source: Takai et al., 2016).

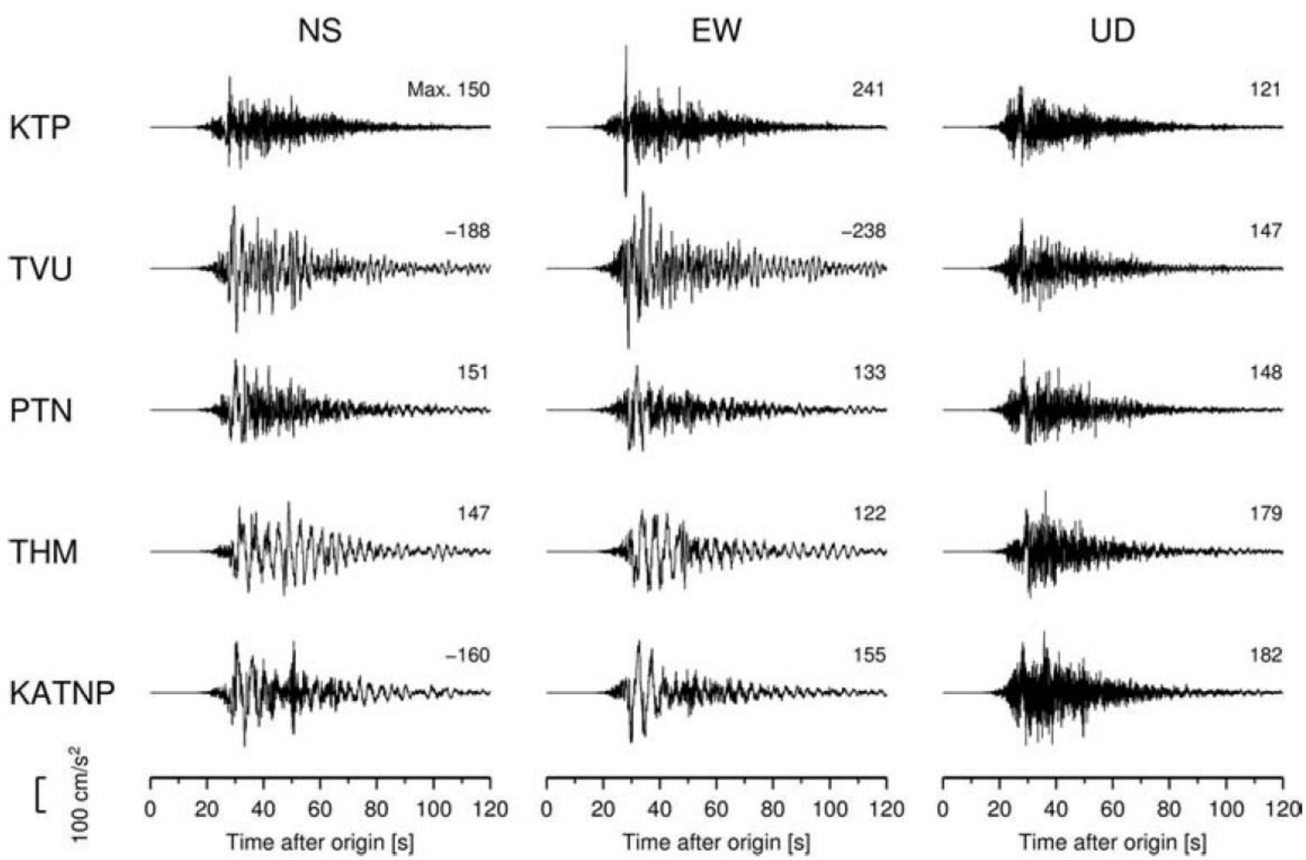

Figure 2-8. Strong ground motion records associated with April 25, 2015 M_w7.8 Gorkha earthquake (source: Takai et al., 2016).

Table 2-1. Peak amplitudes recorded from the strong ground motion stations located within the Kathmandu Valley.

Station Name (location)	Geographic Location (latitude, longitude)	Site Category	Peak Ground Acceleration in g	Peak Ground Velocity in cm/sec
KATNP (US Embassy, Kathmandu)	27.71235, 83.31561	Soil	0.16 (N-S)	107 (E-W)
DMG (Lainchor)	27.7193, 85.3166	Soil	0.15 (N-S)	63 (E-W)
KTP (at Kirtipur Municipality Office)	27.68182, 85.27261	Rock	0.24 (E-W)	52 (N-S)
TVU (Central Dept of Geology, Tribhuvan Uni.)	27.68072, 85.3772	Soil	0.24 (E-W)	99 (N-S)
THM (Univ. Grants Commission, Sanothimi, Bhaktapur)	27.68082, 85.31897	Soil	0.15 (N-S)	90 (N-S)
PTN (Pulchowk Campus, Tribhuvan Uni.)	27.68145, 85.28821	Soil	0.15 (N-S)	74 (N-S)

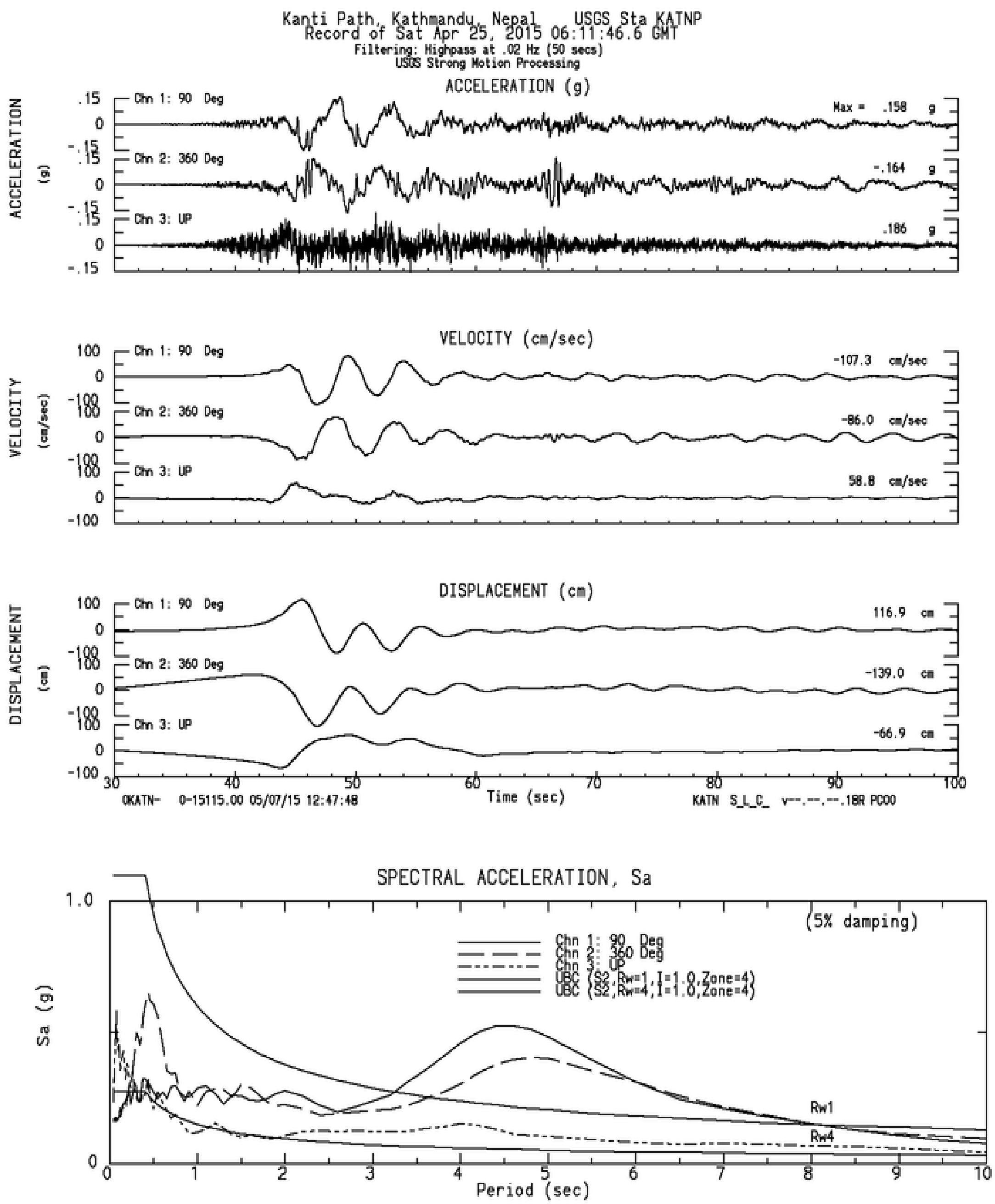

Figure 2-9. Strong ground motion records associated with April 25, 2015 M_w7.8 Gorkha Earthquake for the KATNP station. The top three plots show acceleration, velocity, and displacement records of three components of ground shaking. The bottom plot shows 5% damped pseudo elastic response spectrum (source: CESMD, 2015).

2.7 AFTERSHOCK SEQUENCE

The April 25 Gorkha Earthquake mainshock was followed by a series of large aftershocks that continued for months. 300 M>4 aftershocks were recorded in the first two months, with 130 M>4 aftershocks in the first week along the entire rupture area (USGS, 2015a). Figure 2-10 shows the location and timelines of the aftershocks in which the colors of the symbol indicate the number of days since the April 25 mainshock, and the sizes of the symbols indicate the magnitude of the aftershock. As shown in this figure, the mainshock rupture propagated east from the hypocenter towards Kathmandu.

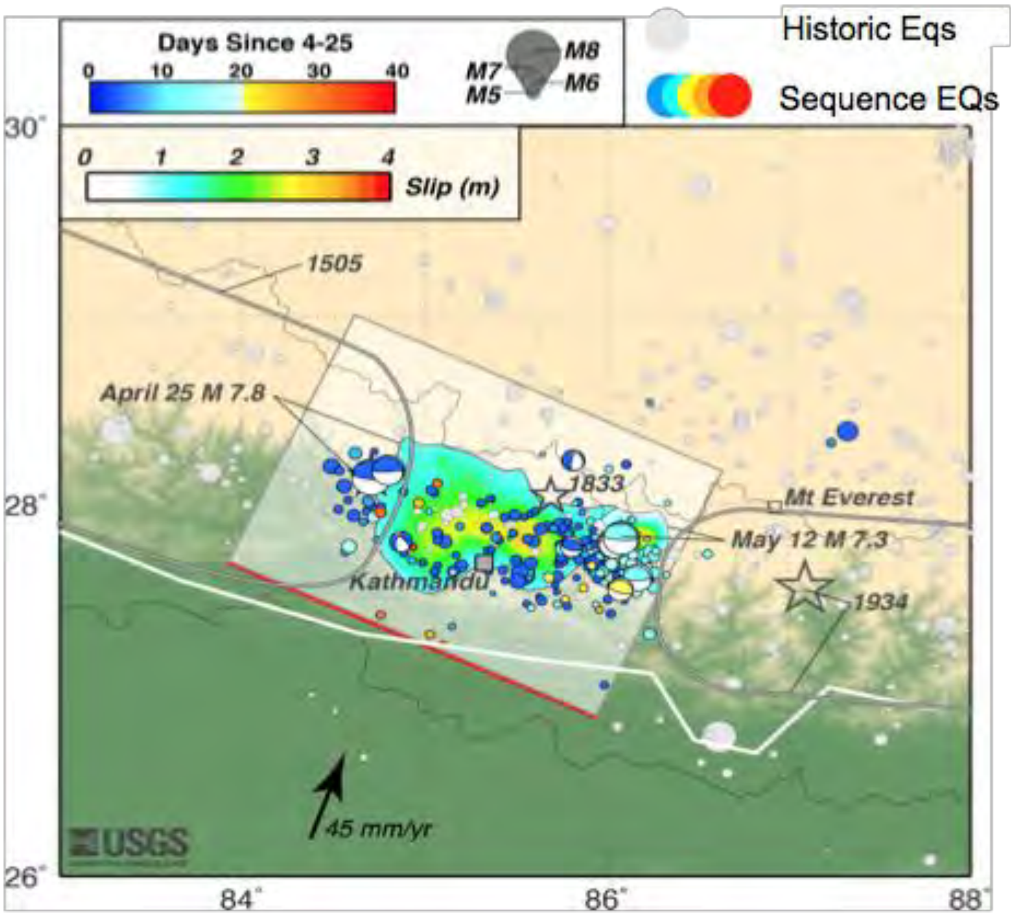

Figure 2-10. Plot showing the location of the mainshock and subsequent aftershocks (colored points) with colors indicating the duration since mainshock. Gray points show the locations of key historic earthquakes recorded in the region. These earthquake locations are superimposed over a color-coded slip map (source: Hayes et al., 2015).

Among the hundreds of aftershocks, the largest was the M_w7.3 aftershock on May 12, 2015 at the NE extent of the mainshock rupture. The slip was close to 4 m but on a fault plane that was roughly 40 km long and 30 km wide; the epicenter was roughly 80 km east, northeast of Kathmandu (Hayes et al., 2015). The strong aftershock was located in an area that was considered a 'seismic gap' between the April 25, 2015 and 1934 earthquake (described in Chapter 1, Section 1.2), and it caused an increase in aftershock activity in the eastern area.

The response spectrum analysis of mainshock and aftershock records at the KATNP site indicated that, unlike the mainshock records, the key aftershock records are in good agreement with the ground motion prediction models (Moss et al., 2015) and illustrated in Section 2.9. Both mainshock and aftershock records at KATNP also demonstrated the influence of directionality in which the east-west component showed relatively higher peaks at long period (or low frequency, <0.3 Hz), while the north-south component showed stronger peaks at short periods (or high frequency, > 1 Hz) (Figure 2-11).

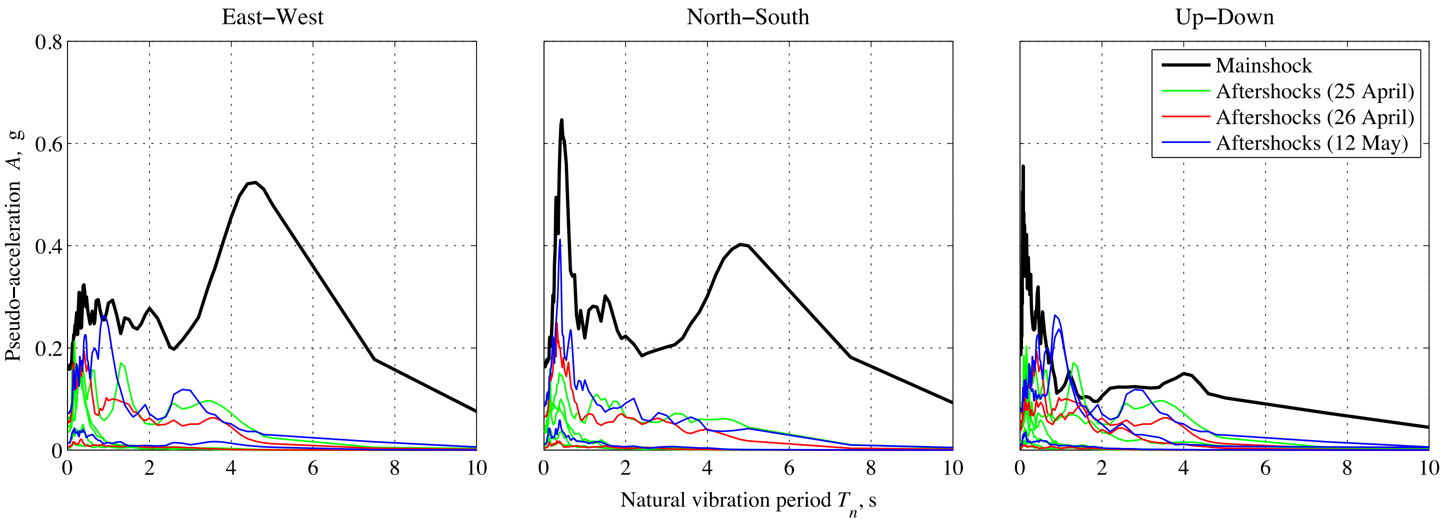

Figure 2-11. Response spectrum plots showing comparison of peak response accelerations of M_w7.8 mainshock and the subsequent aftershocks at various period ranges for the three components of ground motions (source: Erol Kalkan, USGS).

2.8 POPULATION EXPOSURE TO HAZARD

The USGS Prompt Assessment of Global Earthquakes for Response (PAGER) system provides rapid estimates on earthquake shaking, population exposure and the likely ranges of fatalities and economic impact immediate following a significant earthquake anywhere in the world (http://earthquake.usgs.gov/data/pager/onepager.php). The PAGER system estimated that over 6 million people experienced very strong to severe ground shaking (Modified Mercalli Intensity VII+) during the M_w7.8 April 25 Gorkha earthquake, and it was felt by more than 142 million people from Nepal, India, and China (USGS, 2015b). Figure 2-12 shows a Google Earth visualization of the earthquake population exposure as a function of shaking intensity.

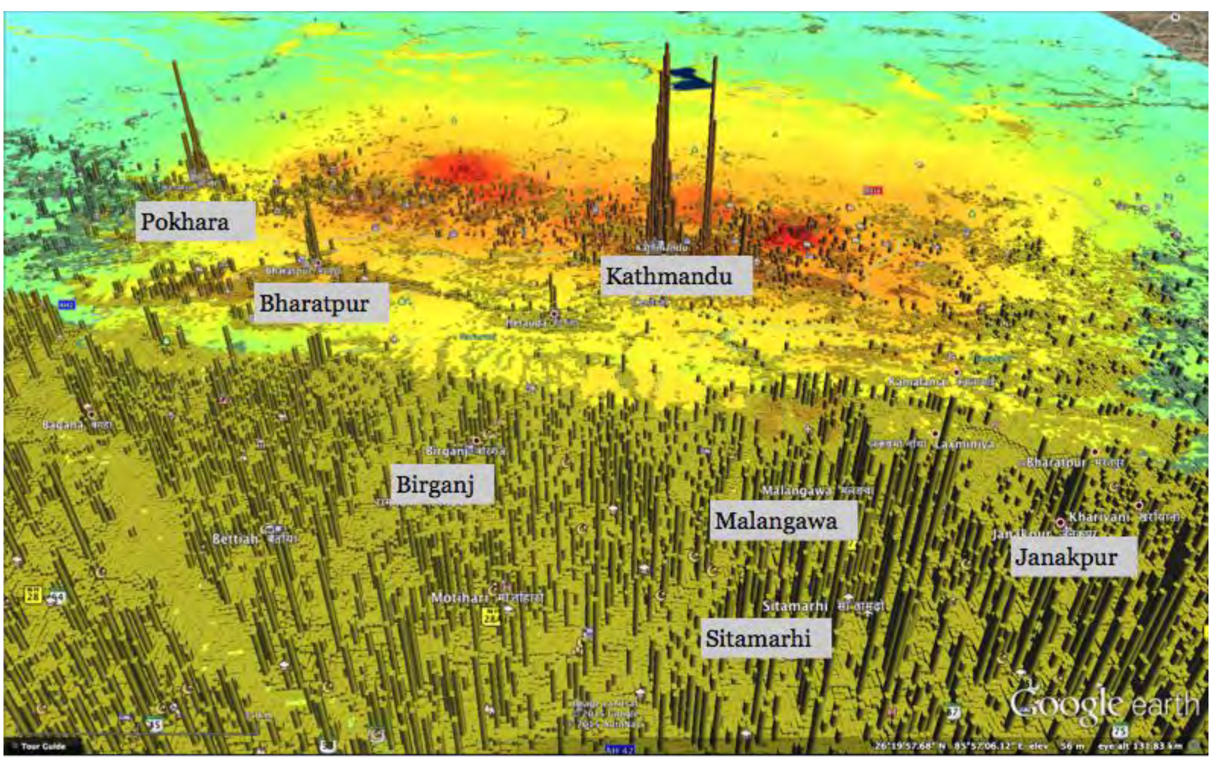

Figure 2-12. A visualization of population density overlaid on the Google Earth Platform showing areas of dense population exposure and zones of strong shaking intensities generated after the M_w7.8 earthquake (source: USGS, 2015c).

The bar plots show the population density per square kilometer grid spacing that experienced specific levels of ground shaking intensity. The hot colors (red and dark orange) indicate areas of severe shaking while the cooler colors (yellow and light green) indicate areas of moderate shaking. As shown in figure, the areas of severe shaking (shown with red color) were restricted to the epicentral regions whereas much of the high population density areas (e.g., the Kathmandu Valley) experienced comparatively lower shaking intensity.

2.9 COMPARISON OF GROUND MOTIONS

Figure 2-13 shows the response spectrum obtained from the KATNP station for the mainshock and the aftershock which is compared with a standard ground motion prediction equation (GMPE) based spectrum after incorporating the site soil correction using the USGS global Vs30 calculator (http://earthquake.usgs.gov/hazards/apps/vs30/). For the mainshock record, the analysis shows that at the low period range (< 1 sec) the observed ground motions were significantly lower than the standard GMPEs mean estimate. Unlike the mainshock records, the aftershock records are in good agreement with the ground motion prediction models.

The strong motion data from both the mainshock and a number of subsequent aftershocks recorded within the Kathmandu Valley displayed some unique characteristics. In general, the ground motions associated with the aftershock records are in good agreement with ground motion prediction equations. The mainshock records showed low peak ground accelerations (< 0.2 g), high velocities (> 100 cm/s), and high long period spectral accelerations (> 0.5 g at 4.5 sec period). The mainshock record showed relatively low peak spectral accelerations at short period range (< 1 sec) but a strong spike at 4.5 sec. Most buildings in Kathmandu Valley are low to mid-rise RC frame with infill masonry wall constructions. Buildings of this height have natural periods of vibration well below 4.5 sec. Consequently, these buildings most likely did not experience the strong pulse of accelerations associated with the 4 to 5 sec period range. This burst of energy at long period within the Kathmandu Valley is an unique characteristic of the Gorkha Earthquake mainshock record. Access to additional strong ground motion records complemented with detailed macroseismic as well as site-specific engineering investigations could further assist to understand the influence of such strong motions on the performance of buildings.

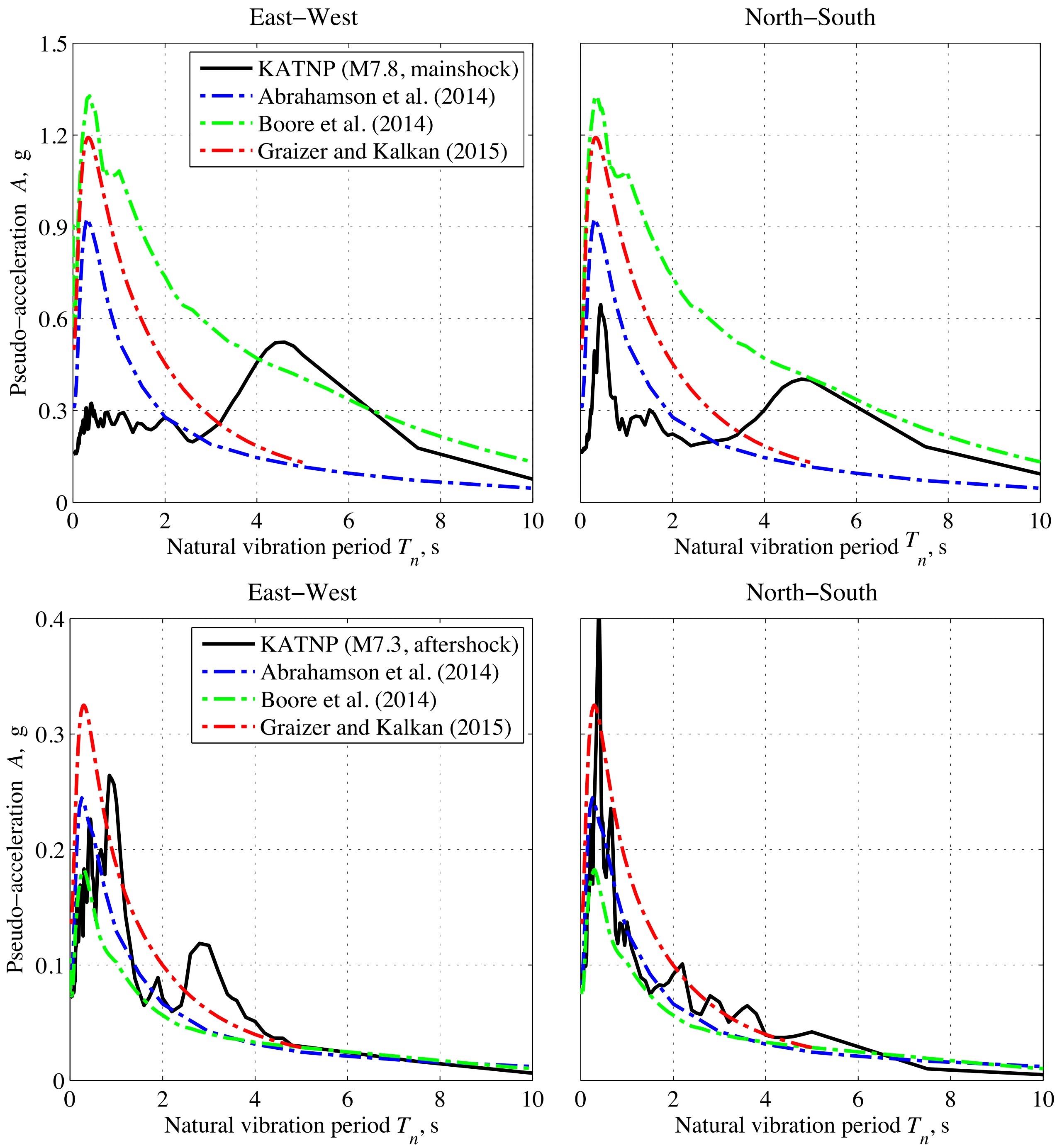

Figure 2-13. A comparison of observed ground motions during the mainshock (top panels) and aftershock (bottom panels) with respect to three ground motion prediction equations (Abrahamson et al., 2014; Boore et al., 2014 Graizer and Kalkan, 2015) (source: Erol Kalkan, USGS).

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CHAPTER 3

GEOTECHNICAL IMPACTS

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Acknowledgements:

The author gratefully acknowledges support from GEER (Geotechnical Extreme Event Reconnaissance), whose Team B members generously met with the EERI team upon its arrival to exchange Information on observed earthquake damage, discuss logistical constraints, and minimize duplication of reconnaissance efforts. Their insights were critical in determining where to focus EERI team geotechnical observations, thus this chapter should supplement the findings in the GEER Report (GEER, 2015). The close collaboration between EERI and GEER teams avoided duplication and significantly increased efficiency to cover a wider and more diverse area. Early access to records from other reconnaissance teams—including the Japanese Society of Civil Engineers and Japanese Geotechnical Society, (Pokhrel, et al., 2015), United States Geological Survey (USGS), and United States Agency for International Development (USAID, 2015)—was also appreciated and helped determine where the EERI geotechnical reconnaissance effort should be focused.

3.1 GEOTECHNICAL FOCUS FOR EERI TEAM

The EERI team noted that earlier investigations focused on locations within the Kathmandu Basin as access to many rural areas was restricted by road damage and logistical constraints (GEER, 2015, Pokhrel, et al., 2015, USAID, 2015). While the GEER Team B did visit selected areas outside Kathmandu urban area, they focused on earthquake impacts on steep slopes in general, roads, and the hydroelectric power generation network. Their report details much of their work around Kathmandu and provides in depth details of their reconnaissance missions to outlying rural areas (GEER, 2015).

The geotechnical and structural engineering members of the EERI team reviewed the available information, and a decision was made to deploy the EERI geotechnical team to Sindupalchok and Dolakha Districts. The reasoning was to observe the damage in the May aftershock epicentral area and to assess earthquake impacts on the rural communities with focus on geohazards and their effects on buildings and infrastructure. The EERI observations and interpretations from a geotechnical perspective are detailed in this section.

3.2 GROUND ENGINEERING ISSUES AND EARTHQUAKE IMPACTS

Both Japanese and GEER teams observed localized liquefaction and associated lateral spreading in the Kathmandu urban area and the surrounding area associated with the Kathmandu Valley. Kathmandu Valley is an approximately 500 m deep basin and former lake bed filled with clays, silts, and sands (Piya, 2014). On several occasions, seismically triggered liquefaction caused foundation distress, manifesting as building and structural tilt and settlement. The most notable liquefaction manifestation was observed in Mulpani, northeast-east of Kathmandu, where carrots were ejected out of the ground (see Figure 6-26 in GEER, 2015). Lateral spreading was noted where 'free edges' existed and saturated ground was able to move towards the free edge. The most notable lateral spreading failures were report by the GEER team adjacent to moraine glacial lakes and near hydro power station inlets and channels. Lateral spreading in the Kathmandu Valley was limited in extent. Further details are provided in GEER Report Chapter 6 (GEER, 2015).

Many teams, including the EERI team, visited Lokanthali and part of the Araniko Highway between Kathmandu and Bhaktapur (Figure 3-1), where several buildings had severely tilted. Major cracking of the ground with approximately 2 m deep fissures and about 1.2 m vertical settlement occurred near sloping ground. The multi-lane highway crossing this area was significantly damaged, but temporary filling allowed traffic to flow. The general area is known to be underlain by 'black cotton' soil, a silty clay and potentially liquefiable deposit that is often inferred to be manmade fill, and anecdotally poorly compacted. The highway crosses in this locale a depression with a small river at the base and features several embankments, including a Terra Armee embankment comprising of reinforced concrete precast panels with internal metallic strip reinforcement stabilizing the soil structure.

Other major earthquake related geotechnical issues were associated with significant ridge amplification effects and strong directivity of seismic shaking. Both effects manifested mainly in rural areas where townships are located along ridgelines. Ridge amplification and directivity caused substantial foundation distress, which in turn resulted in poor overall building performance.

Rock falls and land slips on steeper terrain were frequently observed outside Kathmandu. Rock falls were triggered due to intense shaking of the steep terrain and in many instances caused road closures and hit dwellings. Landslides, some comprising substantial volumes of material, mainly affected the rural road network and main highways leading to the northern border with China. The Singati Township in the Dolakha District in particular was significantly affected by rock mass failures (Figure 3-2) and is described in detail in Section 3.7.

Figure 3-1. Araniko Highway damage, showing tilting building on the left-hand side and settlement center far, Lokanthali 27º40'28.71''N 85º21'42.54''E (photo: Jan Kupec).

Figure 3-2. Singati Township, Dolakha District affected by cliff collapse and rock mass failures from an approximately 50 to 75m high near vertical slope, 27º44'15.49''N 86º9'50.16''E (photo: Jan Kupec).

3.3 EARTHQUAKE SEQUENCE AND AFTERSHOCK CLUSTERING

The approximate location of the main earthquake event (M7.8) on 25 April 2015 was reasonably well predicted some decades ago, and the Nepalese Building Code already accounted for this increased risk by requiring higher design actions to be considered to the west of Kathmandu. The major aftershock (M7.3) on 12 May 2015 was located approximately equidistant between the 25 April 2015 and 1934 earthquakes epicenters in what could be considered a 'seismic gap' and was in close proximity of the 1833 earthquake epicenter (Figure 3-3).

Of interest was the high frequency of smaller aftershocks and their clustering around the epicenter of the 12 May 2015 earthquake. The EERI team focused their investigations around the affected area to observe how the community, buildings, infrastructure, and roads were affected by ongoing and frequent aftershocks. From a geotechnical perspective, slope stability in an active aftershock environment was of interest.

See Chapter 2 for more detail on the seismological and ground motion aspects of this main shock and major aftershocks.

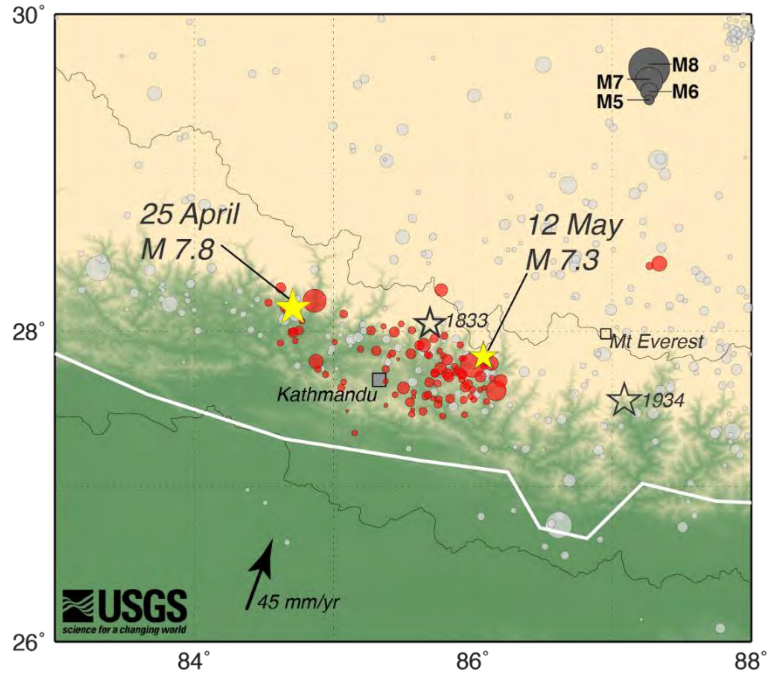


Figure 3-3. USGS representation of the early Nepal earthquake sequence (USGS, 2015).

3.4 SLOPE STABILITY MODELLING

Early modelling of slope performance in Nepal was available on arrival in Kathmandu. The University of Michigan released data about potential slope instability, including density (number of landslides per given area), landslide depths and volumes, as shown in Figures 3-4 and 3-5 (Clark, et al., 2015). Further information was sourced from the University of Michigan website, and data was discussed with Professor Marin Clark (2015). Additional data on landslide distribution was obtained from the Earthquakes without Frontiers website as shown in Figure 3-6 (Earthquakes without Frontiers, 2015). Thus, there was an expectation that slopes were affected by seismic shaking. The GEER Team conducted extensive assessments of slope instability along road corridors and major rivers (GEER, 2015). The EERI geotechnical team confirmed observations of slope instability by comparing modelled and actual slope performance along the Tama Koshi River to the north of Singati township towards the Chinese Border. Modelled slope performance matched well with observations on the ground. In many instances, the slopes were still very active and frequent rock falls were observed while on site.

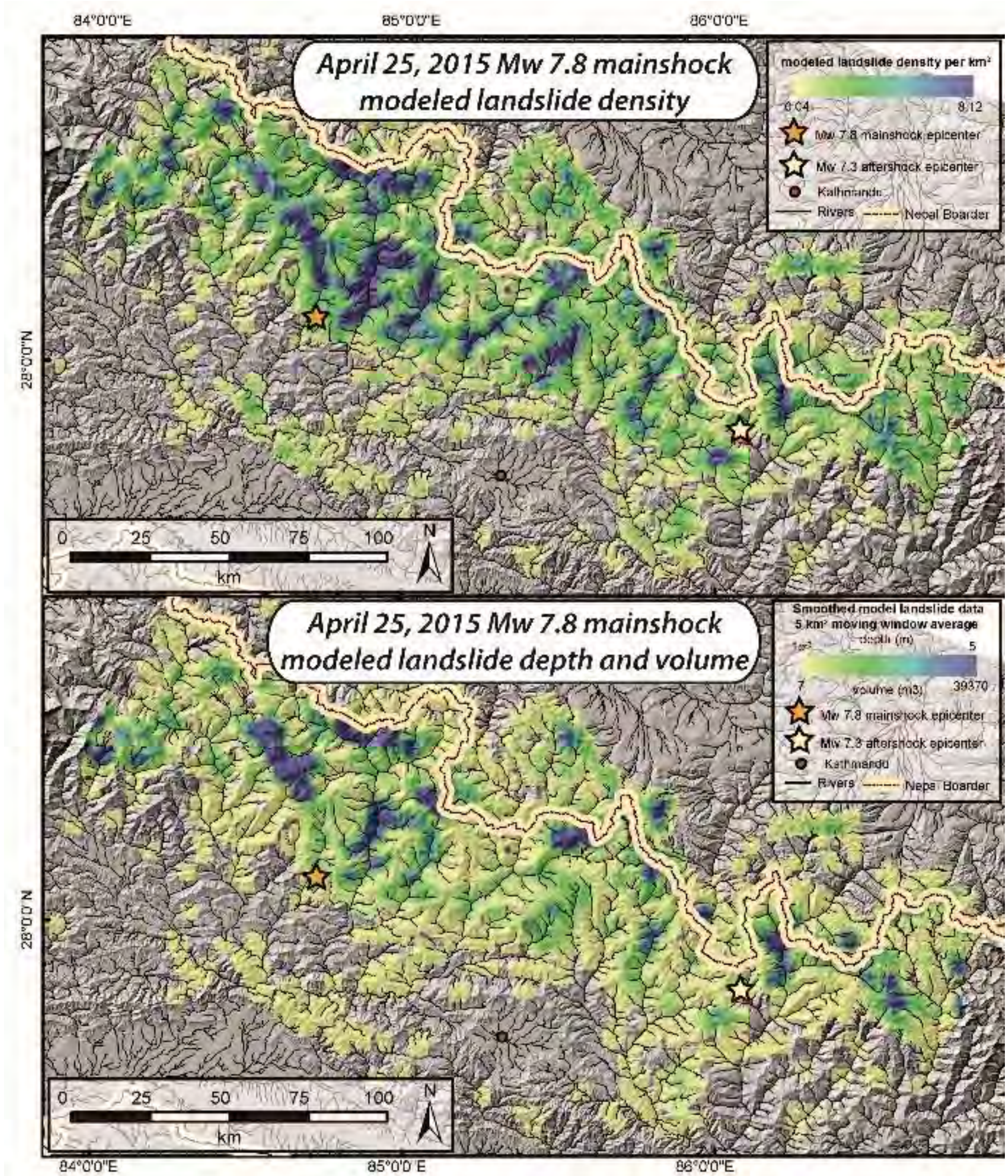


Figure 3-4. Comparison of the modelled earthquake triggered landslide distributions for the 04/25/2015 Mw 7.8 main shock in Nepal. Data used includes SRTM digital elevation model and USGS ShakeMap version 7 for main shock and version 3 for aftershock (after Clark, et al., 2015).

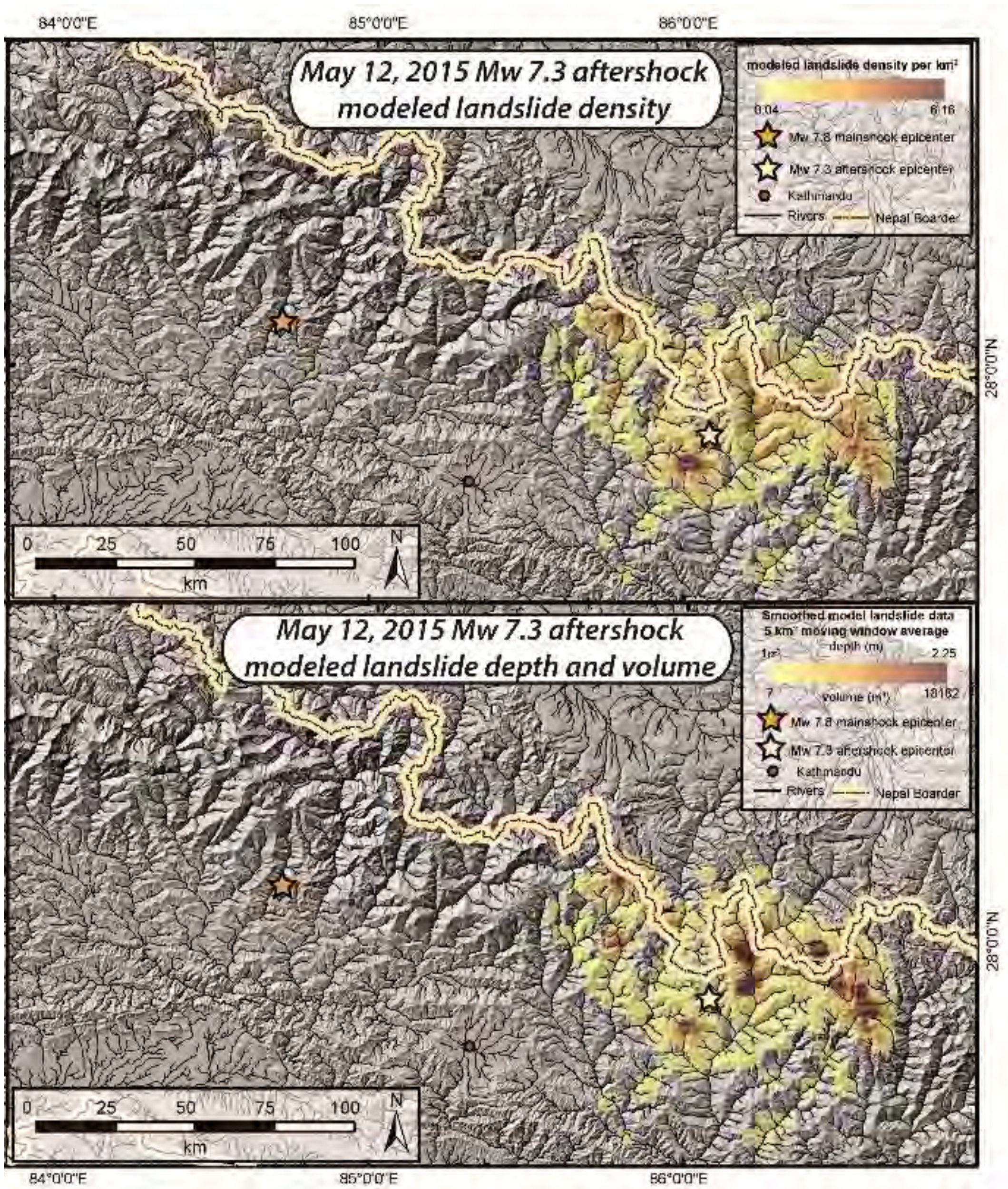


Figure 3-5. *Comparison of the modelled earthquake triggered landslide distributions for the 05/12/2015 aftershock in Nepal. Data used includes SRTM digital elevation model and USGS ShakeMap version 7 for main shock and version 3 for aftershock (after Clark, et al., 2015).*

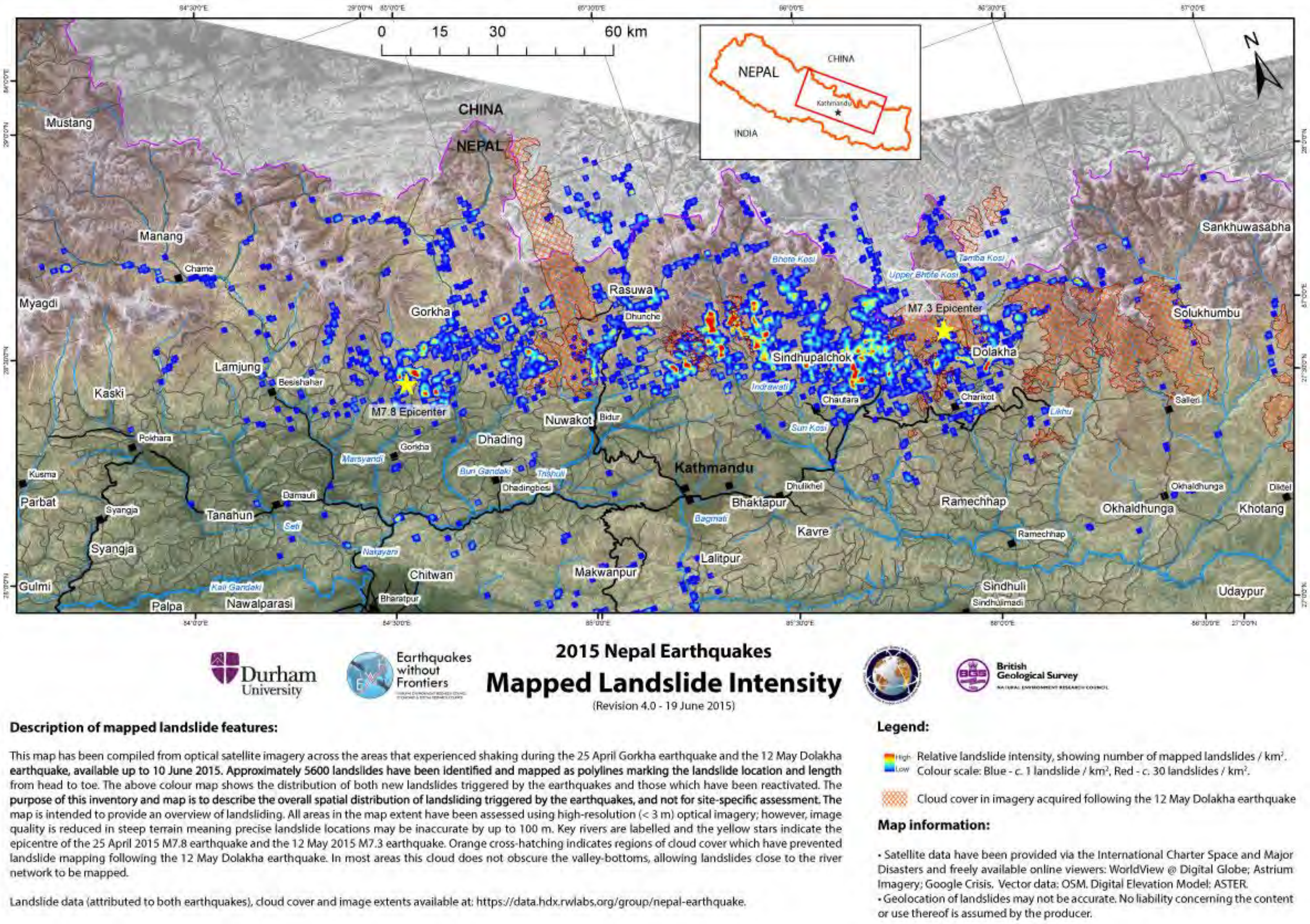


Figure 3-6. Mapped Landslide Intensity (Earthquakes without Frontiers, 2015).

3.5 FOUNDATION PERFORMANCE

Foundation failures were observed in the Kathmandu Valley, but compared to structural damage there was only light foundation damage. Where foundation damage was observed, it occurred in clusters of buildings indicating potentially weak ground in that locale.

Many of the foundation failures that were observed throughout the reconnaissance trip were related to poor ground performance under seismic conditions including lateral spreading, post-liquefaction settlement, seismic overloading of footings, and even traditional soil bearing failures.

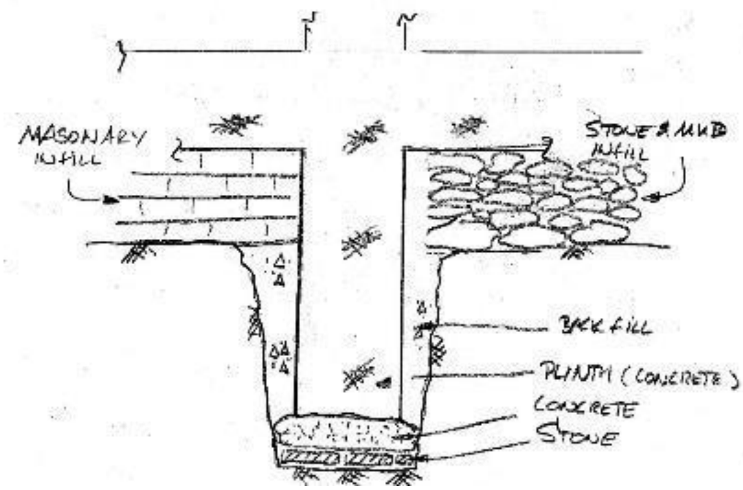
Most townships in rural areas are located along ridgelines due to terrain constraints and the need to preserve the limited arable land for food production. Thus, building foundations in rural areas were often founded on steep to very steep terrain.

Approximately 150 buildings were surveyed by the EERI team in Chautara with various construction types, including unreinforced masonry bearing wall buildings and reinforced concrete frames with masonry infill. Buildings on level ground performed significantly better than those on sloping terrain. See Chapter 5 for details.

Observations of traditional foundation systems indicated that they performed relatively well, but often the unreinforced masonry (URM) superstructure did not fare well. More modern construction types such as lightly reinforced concrete infill frame buildings were damaged at the foundation level due to poor detailing of the concrete frame to foundation connection. Partial collapse or significant foundation damage often caused severe tilt and superstructure damage, including pounding impact and leaning onto neighbouring properties. A notable lack of well-tied and continuous strip footings or pad foundations was observed.

Rebuilding (where observed) used same shallow foundation systems, as shown in Figure 3-7.

(a)



(b)

(c)

Figure 3-7. Example of a typical shallow footing (a) trench under construction in Chautara, (b) sketch of typical shallow footing detail, and (c) photo of typical building foundation (photos and sketch: Jan Kupec).

3.5.1 Non-engineered Foundations

Many unreinforced masonry buildings in older parts of Kathmandu, Bhaktapur, and rural bazaar towns use non-engineered foundation systems often employing timber columns directly founding on large stone plinths, as shown in Figure 3-8. The plinth or stone slab was inferred to be often located on geotechnically stable ground due to lack of observed deformations at the base. Exposure of selected plinth bases indicated well compacted fill and stone slab creating manmade stable ground.

The column-to-plinth connection is of interest. The plinth has a protrusion that matches a divot in the timber columns and the system uses its self-weight to create a shear resisting connection. In several instances, severe damage of the unreinforced masonry superstructure was resisted by the corners of the building, door frames, or entrances to shop floors where this system was used (Figure 3-9).

Figure 3-8. Example of a plinth and column connection for a traditional stone footing (photo: Jan Kupec).

Figure 3-9. Timber column held in place by stone plinth protrusion despite URM superstructure with significant lean in Dhuliket (photo and annotations: Jan Kupec).

3.5.2 Engineered Foundations

More modern foundation systems often for low rise concrete frame buildings were observed in outlying areas of Kathmandu and rural bazaar townships. The foundation system often comprised a 300 to 450 mm wide by 450 to 600 mm deep trench forming a continuous strip footing along the perimeter of the building. The trench is then filled with a layer of locally sourced stone and/or lean concrete layer. Concrete columns are then formed, and these continue into the superstructure. At ground level, a beam is cast between all columns, and the gap between the beam and the footing trench is often infilled with loose stone or bricks. On sloping terrain, this system often creates a mixture of short and long columns connecting the footing trench with the superstructure.

Poor compaction under the ground floor slab was noted in many instances causing slumping of the fill and damage to the foundation infill walls. On several occasions in very steep terrain, the poorly compacted fill was accelerated by the strong seismic shaking and 'kicked out' the downslope foundation columns causing a complete collapse of the superstructure.

Typical foundation damage included overturning and rotation of foundation elements, crushing and out-of-plane failures of infill (Figures 3-10), and tensile failure of steel reinforcement in the columns connecting strip and pad footings to the superstructure (Chapter 5, Figure 5-4b).

(a) (b)

Figure 3-10. Examples of foundation damage in Chautara: (a) short column and infill damage between ground level and footing, and (b) crushing failure and out-of-plane masonry infill failure of building shown tilting in Figure 5-12a (photos: Jan Kupec).

3.6 RIDGE AMPLIFICATIONS

Amplification-deamplification patterns on slopes lead to a strong energy differential on the upper part of the slope. This effect manifests as increased ground shaking of the ridge and is colloquially known as ridge amplification.

From the site visit of the Gorkha Earthquake areas as described in this report, the landslide frequency was noted to be much higher on or near the crests (ridges) of hills and mountains. The terrain in Nepal mountainous areas is steep, and most of the flatter ground is used for crop production. The rural residential villages and townships are therefore often located on or along ridgelines.

Many local bazaar towns were significantly damaged by what appears to be significant ridge amplification effects.

Also of note were strong directivity effects of earthquake shaking associated with ridge amplifications. The Chautara and Irkhu bazaar townships are located along prominent ridgelines, and significant building damage occurred in both locations, manifesting as building tilt on one predominant direction (NW-SE). See Figure 3-11 as well as Chapter 5, Figures 5-4a, 5-5a, and 5-6 for examples of this type of damage.

Figure 3-11. Example of significant building tilt in Chautara (photo: Hemant Kaushik).

3.7 LANDSLIDES

One of the main objectives of the geotechnical team members of the EERI team was to locate, field survey, and record large landslides and document their impact on the community and infrastructure. The team collaborated with other survey teams and sought local advice on where the potentially largest density of landslide could be found. Access to the landslide areas was an issue.

3.7.1 Infrastructure Impacts

The most abundant type of seismically triggered landslides was in the form of rock falls and slides where individual blocks detached from the rock mass and either slid or toppled on a steep slope. Seismically triggered landslides were noted on many occasions due to steep terrain in Nepal. The northern mountainous areas of Nepal are characterized by rapid riverine erosion creating steep to near vertical slopes. Roads tend to follow rivers and streams, and the road cuts are often in very steep slopes to near vertical slopes that are prone to landslides, including rock falls.

Many landslides, in the form of individual rock blocks, were sitting on the carriageway. These blocks were often quickly cleared to allow traffic flow; but, some larger blocks, which needed to be broken down by machinery before moving, were noted during the EERI site inspections about one month following the trigger events, as shown in Figures 3-12 and 3-13.

Landslides in the form of debris avalanches and mass movement were also noted on numerous occasions (Figure 3-14). Those were more pronounced in the northern Dolakha District and especially prevalent to the north of Singati Township in the Bhimeshwor Municipality along the Tama Koshi River towards the Chinese border.

The Singati Township was affected by a landslide in the form a debris slide (Figures 3-15 and 3-16). Material detached from a very steep and up to 75 m high slope and inundated properties and the main road at the base of the slope. Fatalities were reported in Singati, but the actual number is unknown.

(a) (b)

Figure 3-12. Examples of individual rock blocks along Charikot - Lamabagar Rd (photos: Jan Kupec).

Figure 3-13. Structural damage and rock fall at gabion site in Singati Township (photo: Jan Kupec).

(a)

(b)

Figure 3-14. Examples of typical landslide debris blocking roads (a) along highway northeast from Singati Township along true right (the right-hand side of the river looking downstream) of Tama Koshi River and (b) along Charikot - Lamabagar Road (photos: Jan Kupec).

Figure 3-15. Singati Township landslide (photo: Jan Kupec).

Figure 3-16. Singati Township landslide (photo: Jan Kupec).

Similar, but much larger landslides occurred along the Charikot to Lamabagar Road Highway to the north of Singati, along the Tama Koshi River. The road was frequently blocked by landslide debris that buried roads for lengths of several hundreds meters. The debris often originated from slopes some dozens to hundreds of meters above the road. Due to the steep terrain, the debris continued downslope past the road cuts and in many instances terminated in the river or stream at the slope base. Partial debris blockages of the river were noted along the Tama Koshi River, as shown in Figure 3-17. Due to volume of water being carried and gradient of the river, blockages were all breached and partially eroded.

Figure 3-17. River cutting through landslide debris (photo: Jan Kupec).

Landslide debris affected (buried) more than 15% of the first 5 km of the Charikot to Lamabagar Road Highway to the north of Singati on true-river right as shown in Figures 3-18a and 3-18b. Further exploration by the EERI team was not possible as the road became impassable. Observations from true-river left some further 3 km upstream indicated that the landslide density remained constant. Anecdotal evidence suggested that the majority of the landslide debris was deposited in a strong aftershock rather than the main earthquake event. Interestingly, while the team was on site, individual rock falls were ongoing with numerous boulders originating high up in the unstable slopes and travelling at great velocity into the river. Villagers interviewed mentioned that the frequency of rock fall significantly increases after a significant aftershock.

Landslide debris also affected road infrastructure including drains, culverts, and especially retaining walls. Rock filled gabion retaining walls are prevalent in Nepal, presumably due to their ease of transportation and construction in steep terrain and ability to use locally available rock fill. Many retaining walls were impacted (directly hit) by large boulders causing significant damage, or in landslide areas the walls retained a large volume of debris which overloaded them. Bulging and severe displacement were apparent causing structural distress (Figure 3-18c). Even removal of landslide debris, where observed to the south of Singati, often resulted in partial collapse of the wall or significant damage, which affected its functionality.

Due to pervasive steep terrain in northern Nepal, avoidance of areas subject to landslides, rock falls, debris avalanches, and debris slides is not a viable option. Many roads will need to be cleared and their performance monitored after prolonged rainfall events, such as the monsoon season, or following future strong aftershocks. The EERI team noted that generally only very basic equipment such as backhoes and excavators were available making the task ever so more difficult.

(a)

(b)

(c)

Figure 3-18. Landslide debris covering road above Tama Koshi River upstream of Singati (photos: Jan Kupec): (a & b) expanded and close-up views of damaged truck on road due to rock fall and land slippage, and (c) view of rock fall over road supported by a gabion wall that has overloaded it and caused the bottom to bulge.

3.7.2 Community Impacts

During the EERI survey in the Chautara bazaar town in the Sindupalchok District, the team interviewed a local municipal engineering representative who indicated that a rural village was significantly affected by a large landslide. The landslide is located approximately 4.5 km to northwest of the main Chautara Township, but more than 45 minutes away if travelling by four wheel drive across rural roads. The local residents referred to the area where the landslide occurred as Herlang Berlang. The landslide can be colloquially described as a cliff collapse, but the engineering classification is a rock topple mechanism (Figure 3-19). Figure 3-19 is taken from the access road looking west. The team eventually reached the top of the cliff and parked along the top of the cliff near the location marked “Road cut” in the figure.

The observed main failure mode was the retreat of a near vertical escarpment or cliff edge. The cliff top edge failed along approximately 300 m of length, and the rocks travelled as a debris avalanche some 200 to 250 m downslope, although individual large boulders travelled as far as 300 m (Figure 3-20). Historic (paleo) landslide debris was observed amongst the more recent debris (Figure 3-21). The paleo debris was much further downslope than debris deposited in the recent event, potentially indicating that greater volumes of debris can be dislodged and travel as a debris avalanche for considerable distances downslope, or that more significant earthquake shaking has occurred in the past which exceeded the threshold acceleration required to activate a very large landslide. The effect of limited rock falls up to certain levels of ground shaking, with a significant increase in rock fall volume once the threshold shaking was exceeded was also noted during the Christchurch, New Zealand earthquake series in 2011.

Figure 3-19. View of landslide from across the valley on the Chautara side about 4.5 km northwest from Chautara township center (photo: Jan Kupec, annotations: Bret Lizundia).

(a)

(b)

Figure 3-20. (a) Birdseye view of Herlang Berlang cliff collapse (source: Google Earth Pro with annotations by Jan Kupec), and (b) view from cliff top with photo location and orientation indicated by triangular mark on image a (photo: Jan Kupec).

Figure 3-21. Debris avalanche and historic (paleo) downslope talus (photo and annotations: Jan Kupec).

At the top of the cliff, there was significant cracking with crack widths in excess of 75 to 100 mm, some 10 to 15 m setback from the cliff edge, indicating that the rock mass was greatly disturbed by seismic shaking (Figure 3-22). The cracking exhibited both horizontal movement as well as some vertical deformations. Vertical deformations were most notable within the first 10 m from the cliff edge and included up to 75 mm of settlement. Fine cracking (smaller than 5 mm) was noted up to 30 m distant from the edge. A road cut near the northeastern edge of the landslide showed that cracking continued vertically into the rock mass. A crack (5 to 10 mm in wide) was traced through the entire 5 m high road cut and then continued for another 100 m as a semi-continuous crack along the cliff top, some 15 to 20 m away from the cliff edge. The crack pattern is indicative of rock mass damage due to severe shaking.

(a) (b) (c) (d)

Figure 3-22. Expanded and close-up views of (a & b) typical cliff edge cracking approximately 15m back from the cliff edge and (c & d) typical ground cracking near cliff edge (photos and annotations: Jan Kupec).

Near the midpoint of the escarpment were some isolated structures including small temples and cliff edge fencing. The cliff appeared to have retreated in this location some 5 to 7 m. Severe shaking damage was also apparent indicating significant ridge amplification on the escarpment edge causing cliff edge retreat, structural collapse, and initiation of a debris avalanche. Anecdotal evidence suggests that several houses of a small village at the base of the cliff were hit by the debris avalanche (cliff collapse debris inundation) and fatalities occurred. The dwellings were buried in their entirety, but due to earthquake timing most residents were working away from the village.

While undertaking our field surveys at the cliff top, the EERI team met an eight-year-old female survivor of the cliff collapse. She was buried in landslide debris and dug out by her relatives, and we believe that the remainder of her family perished in the landslide debris inundation. We met her with her close relative who now looks after her in the relocated village. This encounter highlighted and brought home the severe impact uncontrolled geohazards have on vulnerable communities.

Figure 3-23. Young survivor of the Herlang Berlang landslide (photo: Jan Kupec).

The residents pointed out that they have relocated their temporary dwellings to a nearby ridge (Figure 3-19), away from potential debris avalanche talus (runout material) but sought assurance that they did not expose their families for further debris inundation and rock fall. This highlighted the need for rapid field assessment of places that may be vulnerable.

Several methods exist that quantify and qualify the debris runout distances from which vulnerability or risk can be determined. Simple graphical methods were developed in the early 1930s. The Angle of Reach (Fahrboeschung Angle) approach was pioneered by Heim (1932) based on his experience in the European Alps. Further research and modifications of this approach were made by several researchers including Hungr et al. (2005) as shown in Figure 3-24. Hungr indicated that there are strong relationships between horizontal and vertical distances from the source area (say cliff edge) that can be used for rapid hazard assessment. Thus, basic landslide geometry or ballistic analysis (how boulders and debris move downslope under gravity) can be used to predict how far individual rock blocks or the main debris talus material will travel on an inclined surface. The analysis is based on observations of past examples of debris moving downslope.

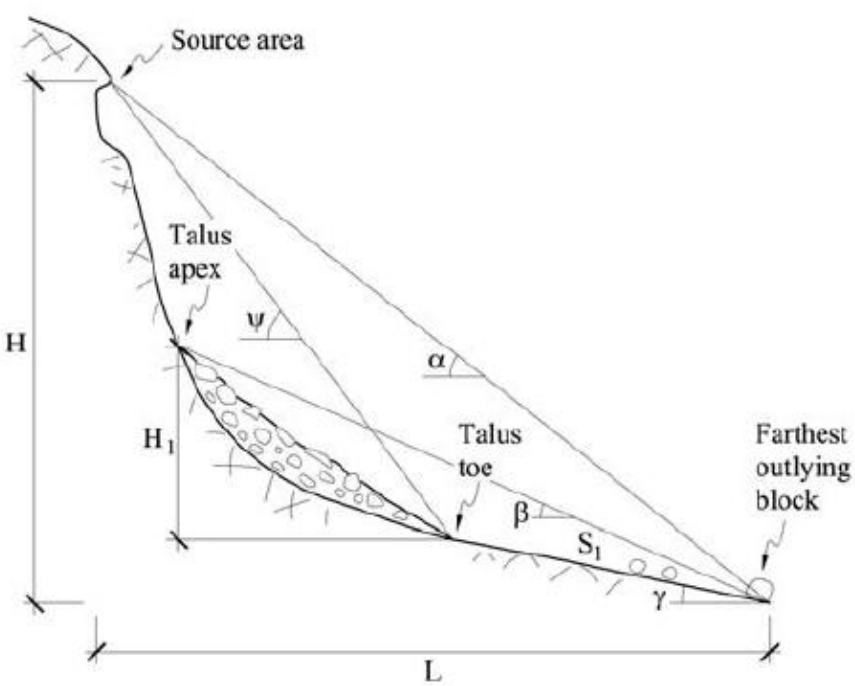


Figure 3-24. Geometrical variables to determine debris run out distances. Note: vertical drop (H), travel distance (L), reach angle (α), shadow angle (β), source-talus angle (ψ), substrate angle (γ), and shadow distance (S_1) are after Hungr et al (2005).

Massey et al. (2012) have used a very similar approach to determine the reach of seismically triggered rock fall on the Port Hills of Christchurch, NZ. The method was field calibrated and despite data scatter consistently indicated that for shadow angles (angle [β] between the horizontal plane and top of the debris talus apex) lower than 21 degrees the risk of being intercepted (hit) by rocks is negligible. The risk of being hit by rocks or debris increases rapidly for shadow angles in excess of 24 degrees. Similarly, a Fahrboeschung Angle (angle [α] between the horizontal plane and the top of the slope or cliff) of less than 31 degrees indicates low to negligible risk.

In the NZ based GNS study, the risk was expressed as Annual Individual Fatality Risk (AIFR), but other measures can be determined to provide a rapid vulnerability assessment. In New Zealand the use of shadow and Fahrboeschung Angles are now more common and rapid assessments can be made. The use of this system allowed a rapid debris run out distance assessment following the 14 February 2016 Valentine's Day Earthquake in Christchurch, New Zealand, and therefore enabled first responders to access slopes covered in fresh rock fall debris.

The EERI team feels that there is a need for a simple field assessment or guide to enable first responders and those facilitating initial stages of recovery to determine the risk from geohazards such as cliffs and rock slopes without a geoprofessional being present. The above example using Fahrboeschung [α] and Shadow [β] Angles provide some simple geometrical rules to enable very basic quantitative risk assessment from rock fall. However, if the debris volumes are large (>10,000m^3) or the terrain is complex, these simple rules should not be relied on and a geoprofessional may be required. Further research is required so that rapid field based assessments can be developed for use in emergency and initial recovery stages.

3.8 SUMMARY OF GEOTECHNICAL FINDINGS

The geotechnical effects from the main earthquake sequence in Nepal can be summarized as follows:

- Limited geotechnical damage occurred in the Kathmandu Valley and where observed, damage was localized.
- Shallow foundation systems are common in the urban and rural areas. Often, they have little to no geotechnical engineering input, but if built well, they performed well.
- Based on damage surveys, we infer that buildings built on level ground typically performed noticeably better than similar buildings on sloping terrain.
- Traditional foundations for low rise buildings in rural areas performed well, but unreinforced masonry or stone masonry superstructures often failed.
- Rural housing is often on or along ridgelines and ridge amplification and earthquake directivity effects were noted on several occasions. Limited consideration during building design appears to be given to ridge amplification effects.
- Rural areas were hit by strong seismic shaking, resulting in activation of geohazards such as land sliding, rock fall, and cliff collapse. Debris run out often caused very extensive building and infrastructure damage with associated loss of life. Notably, bridges appear to be a major exception and mostly they appear to have performed well.
- Effects from the earthquake sequence will manifest for many years. Slope stability will require several seasonal cycles to find a new equilibrium.

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CHAPTER 4
LIFELINES

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Acknowledgements:
We would like to thank the many individuals from the following organizations who met with us, providing valuable information and insight: Civil Aviation Authority, Department of Roads, Department of Water Supply and Sewerage (DWSS), Kathmandu Water Supply (KUKL), Nepal Electricity Authority, and Nepal Telecommunications Authority. We also thank our Virtual Team Collaborator, Lisa Shrestha, for her help in supporting our efforts.

4.1 INTRODUCTION

In this chapter, we summarize the earthquake effects on lifelines, specifically electricity, water supply, sewerage, telecommunications, and transportation (roads, bridges, and airports), as reported by the various operators at the time of the reconnaissance trip. For each lifeline, we briefly describe the state of functioning pre-earthquake and major development projects that were underway, damage and service interruptions caused by the earthquake and aftershocks, restoration and repair efforts, and other relevant issues.

4.2 ELECTRICITY

The Nepal Electricity Authority (NEA) generates, transmits, and distributes power throughout Nepal. Before the earthquake, only two-thirds of the 1,200 Megawatt (MW) estimated annual demand for electricity was being met, and that was supplied almost entirely by hydropower (NEA, 2014). The remaining 400 MW of demand was handled by load shedding (i.e., planned rolling blackouts) up to 12 hours per day in some places. This was despite importing about 250 MW from India at substantial expense. The inability to meet regular demand is in part due to system transmission losses, but mostly due to inadequate generation. To meet the shortfall, several large hydropower projects are currently underway in Nepal that together should more than double the capacity in the next several years, taking advantage of some of the country's huge untapped potential for hydropower. In the meantime, customers—especially critical facilities, but regular residents as well—often have their own batteries and/or generators to deal with the regular load shedding that occurs. Hydropower plants, transmission towers, substations, and switchyards were all generally designed using U.S. codes, with at least the first two considering earthquake loads.

The generation system experienced damage to penstocks and walls; some canal, spillway, and dam crest cracking; and access road blockage, most of which was landslide-related (Poindexter, 2015). About 115 MW of operating hydropower facilities, plus about 1,000 MW of hydropower projects under construction, are estimated to have sustained damage (NPC, 2015). A couple of transmission towers were damaged, but in general, the transmission system, as well as substations and switchyards, performed well. There was severe damage to the distribution system (Figure 4-1), with estimates of about 800 km of distribution lines and 365 transformers out of service (NPC, 2015). Power was mostly restored in Kathmandu within 24 hours, and in other urban areas within one to seven days, although it was longer in the most severely affected districts. Chautara, for example, did not have power for almost two weeks. In the most severely affected rural areas (e.g., Sindupalchowk, Rasuwa, and Gorkha), power was only about 50% restored a month after the earthquake in part due to difficulties accessing the damaged equipment.

Figure 4-1. Electric pole damage that impacted roadways and vehicles (source: EPA, 2015)

For customers in Kathmandu at least, the power interruption was less noticeable than it may have been because they already have batteries and generators to address the normal load shedding. Nevertheless, it is estimated that it will cost 5 billion Nepalese Rupees (NPR) to repair the government-owned power infrastructure (almost 20% of the annual net revenue), and more for the privately-owned facilities. In addition, officials reported that several major hydropower development projects will be delayed at least a year, resulting in approximately NPR 20 billion lost revenue and a substantial set back in the country's development.

4.3 WATER SUPPLY AND SEWERAGE

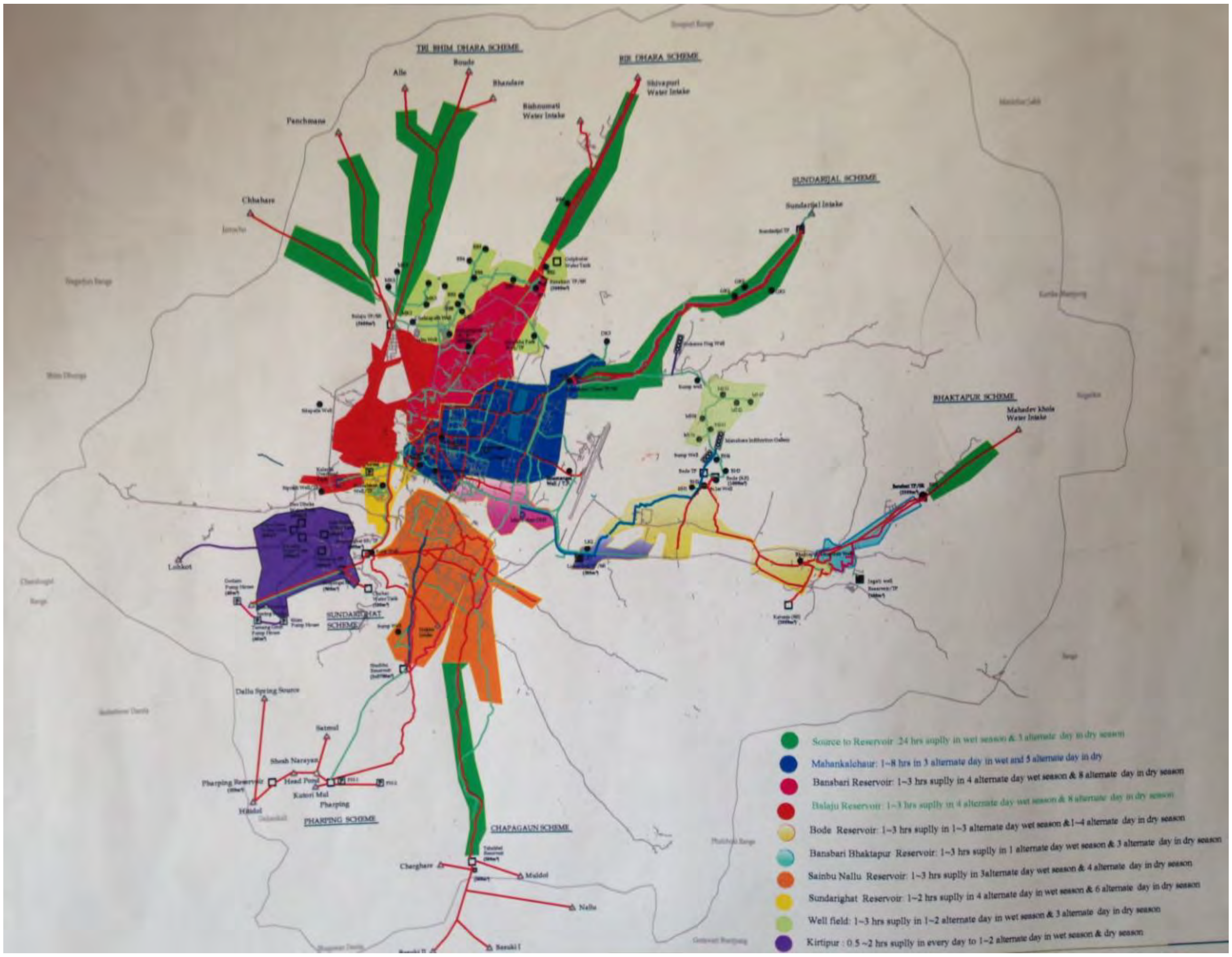
4.3.1 Kathmandu

Kathmandu Upatyaka Khanepani Limited (KUKL) operates and maintains the water supply and sewerage systems in most of Kathmandu Valley. There are 2.7 million people and 200,000 connections in its service area (Bhandari, 2015). The system is comprised of eight subsystems (Figure 4-2), each with a different source and treatment plant. The system also includes 70 tube wells that provide about 30% of KUKL's water. There are 300 km of transmission main and 1300 km of distribution mains, mostly cast iron, ductile iron, and galvanized iron (for distribution), with some newer lines of PVC and HDPE (KUKL, 2015a). Not all homes have private water connections; many use communal wells or taps (Figure 4-3a and 4-3b), especially in more rural areas.

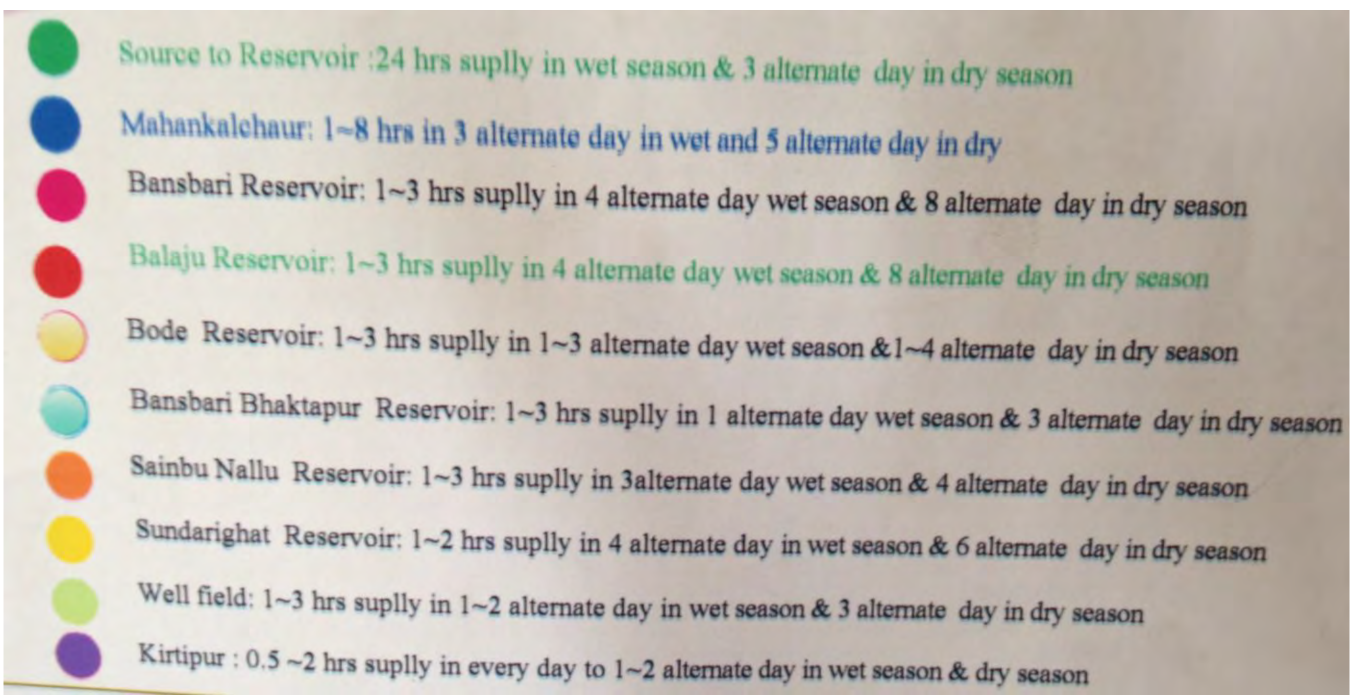
Even before the earthquake, KUKL faced two large challenges—insufficient supply and groundwater depletion. As of 2015, even using tankers to supplement the supply, KUKL is only able to provide 25%-40% of the 370 million liters per day (MLD) demand, depending on if it is the dry or wet season (KUKL, 2015a). As a result, service is intermittent, with some customers served by the main transmission lines near the sources receiving water continuously, but others getting it as little as one hour a week. A schedule determines when water is provided to each portion of the service area. KUKL has two major development projects underway to address the shortfall. The Melamchi Water Supply Project began in 2,000 to add 510 MLD by bringing water from outside the city, and the Kathmandu Valley Water Supply Improvement Project is improving the distribution system. In the meantime, customers have adapted to the incomplete service by digging their own shallow wells and installing rooftop tanks to store water they obtain when it is available (Figure 4-3c). A second major challenge is that as the number of wells has increased dramatically from just a few in the mid-1970s, the groundwater has been depleted. The water table has dropped approximately 30 m, and where they used to get about 2.8 MLD per well, now it is 0.5 MLD. This may pose a threat to the sustainability of the water system and has been the subject of much study (e.g., Pandey et al., 2012).

Earthquake damage included many pipe breaks (especially house connections), leaking mechanical couplings, some silting of wells, and extensive damage to KUKL office buildings. One of the eight subsystems experienced damage when a 35 cm trunk was damaged by landslide. Tanks and treatment plants largely performed well. Power loss was not a big problem. Approximately two-thirds of a million people left Kathmandu following the earthquake, reducing demand. Service was restored within one to ten days, with the outage being unnoticeable to many customers who are used to only intermittent service anyway. Damage is estimated at NPR 210 million, which is about 25% of annual operating expenditures (Bhandari, 2015). Except for NPR 50 million for headpond damage (a headpond is a reservoir above a hydroelectric plant that directs water into the penstocks, which then lead to the turbine), most of the loss is related to office building damage.

As of 2008, the KUKL sewerage system was limited and in poor condition. At that time, there were 93,000 customers connected to it, only one of the four treatment plants functioned, the sewer networks were in bad condition, limited drawings and knowledge of the system existed, and no preventative maintenance plan was in place (KUKL, 2008). Municipalities, customers, and NGOs sometimes construct sewers on their own in an unplanned fashion and typically used septic systems or discharge sewage into rivers located in the valley. To meet this deficit, KUKL has planned the Kathmandu Valley Waste Water Management Project with an Asian Development Bank (ADB) loan that will connect all river outfalls to new treatment plants and improve the existing system over the next few years.



(a)



(b)

Figure 4-2. (a) Map of Kathmandu Upatyaka Khanepani Limited (KUKL) water supply system in Kathmandu (b) with exploded view of legend showing schedule of water availability (source: KUKL 2015b)

(a)

(b)

(c)

Figure 4-3. Common water sources: (a & b) Community spigots and wells in Bhaktapur, and (c) Rooftop water tanks in Kathmandu (photos: Rachel Davidson)

4.3.2 Districts

The Department of Water Supply and Sewerage (DWSS) handles water supply systems and sanitation (includes septic and latrines, in addition to sewer pipes) throughout the rest of the country. Spurred by the United Nations Millennium Development Goals (UN, 2002), Nepal has made great progress toward its goal of universal water supply and sanitation coverage by 2017, increasing water supply from 37% in 1990 to over 80% at the time of the earthquake and sanitation coverage—defined as access to a safe excreta disposal facility—from about 6% in 1990 to over 62% now (MPPW, 2009, DWSS, 2015).

In the more rural areas, water is mostly supplied through small gravity-fed systems with a spring or stream source, serving about 1,000-1,500 people per system. They are managed by local water users groups that coordinate with DWSS. In the earthquake, about 40% of the systems in the 14 affected districts were damaged. Effects included damage to intakes, ferrocement tanks and reservoirs, and pipelines damaged by landslide. Sources were depleted in some places and increased in others. As a result, there are fewer taps functioning, forcing many people to walk much longer distances to get water, a job that typically falls to women and girls (NPC, 2015). In the more rural areas, septic and often self-built soak pit latrines are used for sanitation.

Throughout the country, the United Nations Water, Sanitation, and Health (WASH) Cluster is coordinating relief activities related to water and sanitation, undertaking activities to provide hygiene kits, promote hygiene, provide emergency sanitation (i.e., latrines in camps), provide sustained sanitation (repairing or building new latrines in the community), provide emergency water (temporary access to safe water through water purification or trucking of treated water), and sustained water (repairing normal water supply) (Figure 4-4).

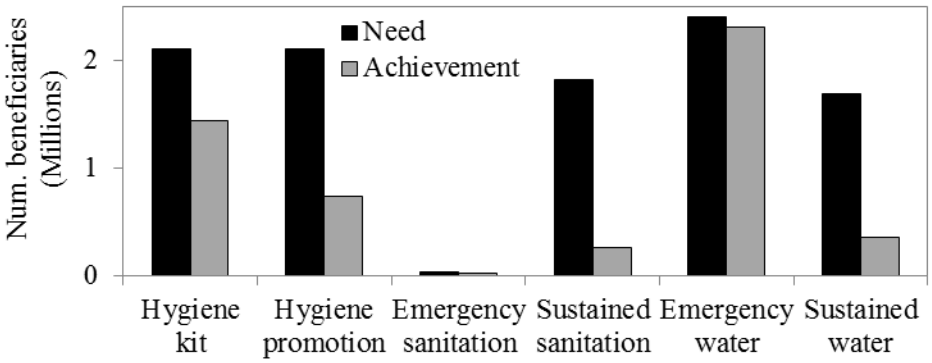


Figure 4-4. United Nations Water, Sanitation, and Health (WASH) Cluster activities in 14 priority affected districts as of July 26, 2015 (Source: WASH, 2015)

4.4 TELECOMMUNICATIONS

Six telecommunications providers serve Nepal with overlapping service areas, including two that provide mobile phone service. There are 23 million mobile phones and 840,000 landlines serving a population of 26.5 million people (NTA, 2015a). In the Kathmandu area, the network is overhead and underground optical fiber; in the rural districts, it is mostly microwave. Due to the high cost of land and difficulty obtaining deed transfer, many mobile towers are on top of buildings (Figure 4-5a), where they are typically anchored and mostly continued to function even when the building was damaged (Figure 4-5c,d). Nevertheless, there were reports after the earthquake of residents requesting to have the towers taken down because they were perceived to be unstable and could possibly collapse.

In the earthquake, approximately 250 (20%) of the 1,240 mobile towers in the eleven most affected districts were down, and that number was reduced to 100 after two weeks by which time about 90% of service was restored (Figure 4-5b). Many overhead optical fiber lines were down, as well as some microwave links. The international link to India remained in service. Many mobile towers had several hours of battery backup to address normal load shedding in the electric system (some had generators as well), but they lost service when the batteries ran out. The internet was down in the Kathmandu Valley for about 24 hours because of power outages, but it was able to serve as an important part of the response. Operators had some spare parts and imported additional ones, which happened quickly. There were some delays getting access to remote damage locations. In all, the telecommunications sector loss is estimated at NPR 8.7 billion (NPC, 2015).

The United Nations Emergency Telecommunications Cluster (ETC) was activated to provide basic security communications services (two-way radio networks) and shared voice and internet connectivity for humanitarian workers. By June 30, the ETC was providing internet connectivity in 15 sites across the affected districts, with more than 1,200 humanitarians from 140 organizations registered to use the services (ETC, 2015). The ETC reported access to remote areas and congestion at the Tribhuvan International Airport in Kathmandu as challenges in delaying deployment of equipment and staff.

Prior to the earthquake, there had been efforts to develop an emergency preparedness plan including coordination with other utilities, but it had not been completed. Following an assessment of the seismic vulnerability of mobile towers five years ago that concluded most were vulnerable to earthquake damage, the Nepal Telecommunications Authority (NTA), the regulatory body for the country's telecom industry, had been working to prepare new guidelines for the construction of new towers and retrofit of existing ones (Kathmandu Post, 2010, NTA, 2015b). Following the earthquake, there are now plans to complete the emergency preparedness plan and tower construction and retrofit guidelines, implement a program to retrofit existing vulnerable towers, develop an emergency backup telecommunications network, and design office buildings for earthquake loads.

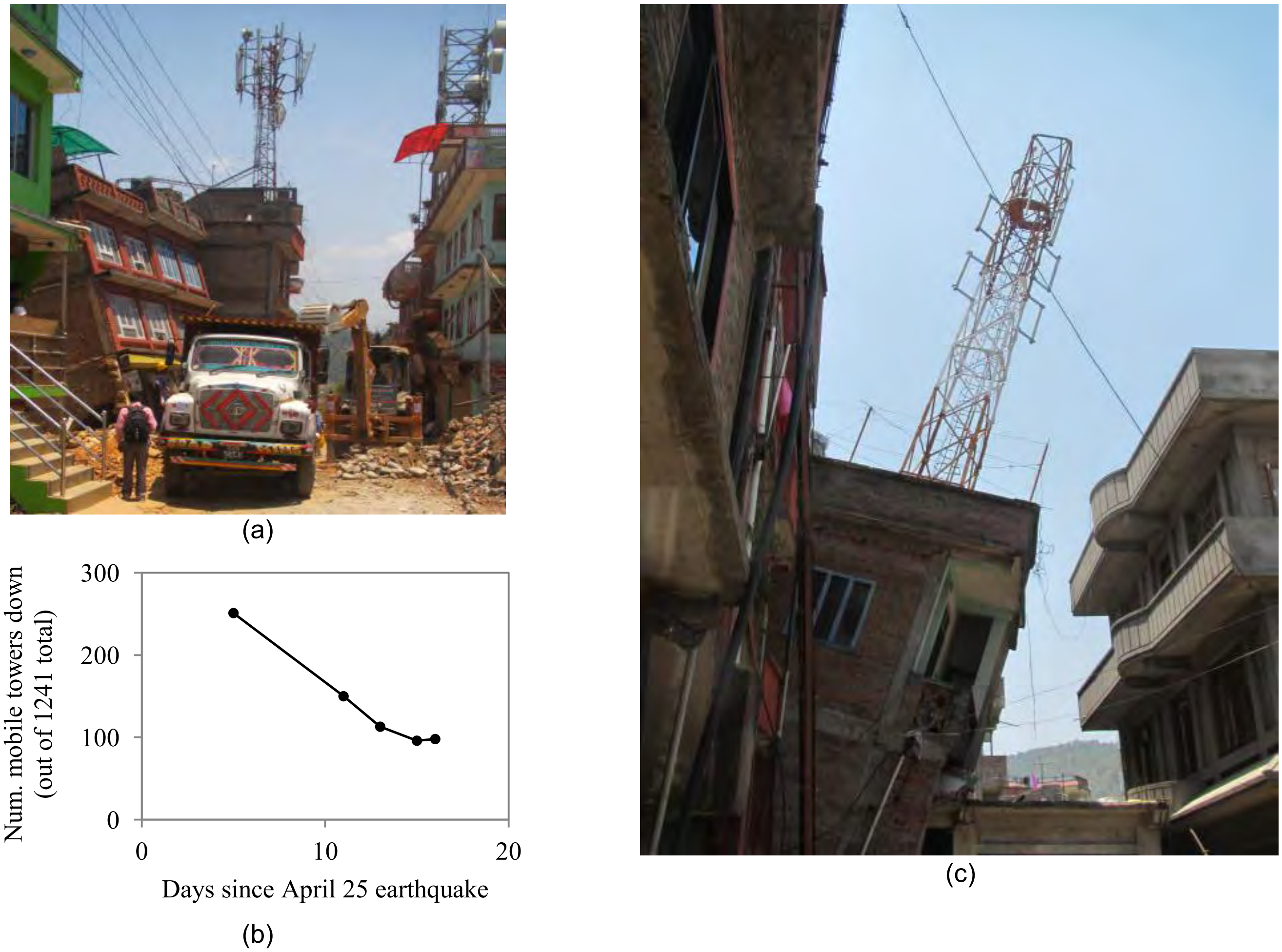


Figure 4-5. (a) Typical installation of mobile towers on building roofs in Chautara (photo: Chris Poland), (b) Number of mobile towers down vs. days post-earthquake (adapted from: NTA 2015c), (c) Mobile tower anchored to roof of a building that was severely tilted in Chautara (photo: Chris Poland).

4.5 TRANSPORTATION

4.5.1 Roads and Bridges

The Department of Roads (DOR) is responsible for the 12,500 km of roads and 1,700 bridges that make up the Strategic Road Network in Nepal, and local municipalities are responsible for the remaining local roads. The strategic road network, which currently includes 51% black top, 35% earthen, and 14% gravel roads, is still in the process of being extended and improved (DOR, 2015b). Roads are typically designed for a 15-year life, and more than 90% of the budget is spent on new roads rather than maintenance. Due to the extremely steep terrain in much of the country and budget limitations, there is not a lot of opportunity for redundancy in the network. Bridges are typically designed following the Indian Road Congress standards.

The earthquake caused substantial damage to roads due to landslides and ground failure, as shown in Figure 4-6 (DOR, 2015a). Officials reported that no bridges collapsed or had to be closed, although there were some problems. With the help of the World Bank and the Japan International Cooperation Agency (JICA), an assessment of damage to bridges is currently underway. The mostly rural roads that were damaged did not typically have pipelines or other utilities co-located with them, so there was little interdependency-related disruption in that respect. Although the DOR had experience clearing roads due to the landslides that are common during the normal monsoon season, there was no specific earthquake response plan. Teams were formed and deployed to clear roads, including help from the Nepal Army and

Chinese Army, who worked together to reopen the main highway between the countries. The DOR's nine heavy equipment divisions, which are normally deployed throughout the country to clear landslides during the monsoon season, were all sent to the affected areas, and additional equipment was borrowed from the private sector as well. The post-disaster needs assessment estimates the transport sector loss at NPR 22.1 billion (NPC, 2015).

Figure 4-6. Araniko highway in Sindhupalchowk District obstructed by landslide (Source: Paudel, 2015)

Within a week, most major roads were open and road access to heavily affected Village Development Committees (VDCs) was possible, but the status of secondary and tertiary roads in many regions remained unclear (Logistics Cluster, 2015c). Almost all roads were open a month after the earthquake (Figure 4-7); however, the situation remained in flux as of the summer of 2015 as aftershocks and then monsoon rains continued to trigger new landslides and flooding that created new blockages over the three months following the main earthquake. For example, the Araniko Highway, a main trade route between Bahrabise and Kodari at the Nepal-China border, was closed due to landslide debris April 30, closed May 14, damaged but passable with only small vehicles allowed May 16-19, closed again May 20 due to debris from landslide, open May 21-June 18, closed again June 19-25, open June 30-July 13, and closed July 14-27 (Logistics Cluster, 2015a).

As severe access constraints continued to impede delivery of relief in the most remote areas a month after the earthquake, the United Nations Logistics Cluster, responsible for providing logistics coordination, ramped up the Remote Access Operations to provide last mile transport to otherwise inaccessible high altitude locations. The aim is to provide immediate relief and help speed recovery for those communities by assessing trail damage, rehabilitating trails, and providing transport by porters and pack animals. The program is to provide sustainable alternatives to air transport as helicopter operations scale down (Logistics Cluster, 2015b,c) (Figure 4-8a and 4-8b).

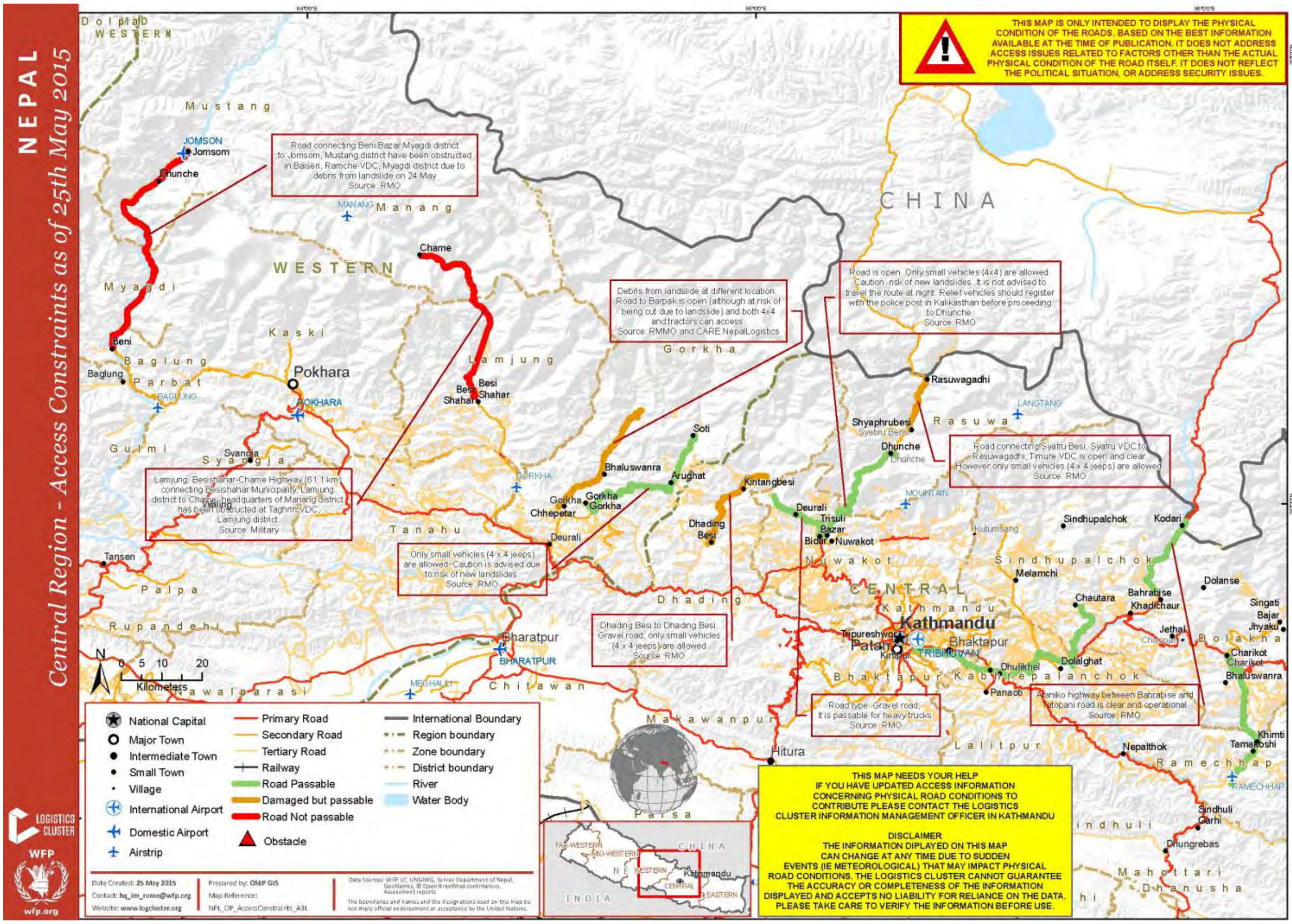


Figure 4-7. Map of central region indicating status of main roads as of 25 May 2015 (Logistics Cluster, 2015a)

(a) (b) (c)

Figure 4-8. (a) Helicopter operations in remote area on May 26 (source: Logistics Cluster, 2015b), (b) Remote Access Operations by pack animal on July 6 (source: Logistics Cluster, 2015b), and (c) Tribhuvan Airport (photo: Chris Poland).

4.5.2 Airports

Nepal's only international airport and hub of all air service in the country is the Tribhuvan International Airport on the eastern side of Kathmandu (Figure 4-8c). The airport suspended operations immediately after the earthquake to assess the status of the tarmac, but reopened within a day and then operated continuously with the help of the Army and Police to process planes and supplies. A rapid visual damage assessment concluded there was minor nonstructural damage but no structural damage to buildings, and no significant damage to the pavement surface of the runway, taxiway, and apron (although some had been anticipated) (TIA, 2015, Pandey et al., 2013). All domestic airports were functional as well, but experienced limited operations.

Although the Tribhuvan Airport was operational, there were some challenges to its operations. The relatively small airport was quite congested because of the large amount of relief coming in. Due to the increase in activity, a maximum total weight limit (aircraft and cargo) of 190 MT was implemented (although the USACE rated the runway capacity at 118 MT). This limited capacity required numerous large cargo planes to be rerouted to India to offload a portion of their cargo before being permitted to land. With only nine parking places for airplanes, limited aircraft slots also became a constraint.

The airport did have a robust post-earthquake emergency response plan in place that was exercised (Pandey et al., 2013). A Humanitarian Staging Area connected to the apron of the Tribhuvan Airport had been opened just one month earlier (WFP, 2015). It served as the main logistics hub, facilitating storage and movement of humanitarian relief items. Further facilitating operations, during the first month of the earthquake response, customs procedures and import duties were largely waived for relief items entering the country (Logistics Cluster, 2015c). The handling of relief continually improved over the first couple weeks as donated equipment and support from international agencies helped reduce offloading time and streamline operations. Airport officials strongly denounced reports that were circulated worldwide that imports of emergency supplies were being purposely detained or turned back in the early days after the earthquake. They insisted that the delays that were experienced were due to runway capacity, staging area availability, and availability of personnel to handle the inbound cargo.

4.6 CONCLUDING THOUGHTS

There was considerable damage and service interruption to the lifeline networks in Nepal. The immediate effects of electric power and water supply interruptions on at least urban consumers were not as noticeable as they may have been since those systems offer only intermittent service under normal times, so many already had alternate ways of obtaining service in place. Nevertheless, the damage will cause substantial setbacks to the active expansion and improvements that have been underway as part of Nepal’s development. While the airport largely continued to function well and served an important role during the emergency response phase, road damage, mostly caused by landslides, caused major problems accessing more remote communities. The telecommunications network performed quite well overall, although several efforts to improve its resilience for the future have already been identified. Overall, the Post-Disaster Needs Assessment estimates that 11% of the total NPR 670 billion loss is associated with these lifelines sectors (NPC, 2015).

Landslides were a major factor in causing lifeline disruptions, and the landslide risk is pervasive across large portions of the country. The monsoons also play an important role in providing some organizations with emergency experience, exacerbating the damage, and interrupting response and recovery efforts. There was little evidence that interdependencies among the lifelines caused any significant cascading failures, with the exception of road damage limiting access to rural areas. Most roads that were blocked did not have pipelines or other utilities co-located with them, and the utilities had systems in place to handle power outages due to the normal load shedding that occurred.

It is important to note that the effects of lifeline damage and disruption are quite different in Kathmandu, urban areas in the districts, and the villages in the more remote areas, due to differences in the pre-earthquake physical systems in place, how they are operated and managed, the roles they play in everyday life, and the ability of the people to adapt and cope with interruptions.

In general, there was limited pre-earthquake preparedness in place among the utilities, with some notable exceptions, such as the airport disaster planning. Most organizations saw the need for better planning and construction to avoid losses in the future, however, and discussed intentions to reduce risk moving forward. In particular, with large capital investments being made in roads, water supply, sewer treatment, and hydropower, it is important that the new construction consider earthquake risk so that those facilities are not similarly vulnerable in future earthquakes.

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CHAPTER 5
BUILDINGS

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Acknowledgements:
We would like to thank the following individuals and organizations for their assistance and insights:

- NSET for NSET for coordination, logistics, and linkages to local individuals and organizations in Nepal;
- Prof. Prem Nath Maskey, Tribhuvan University, Kathmandu, Nepal and Prof. Sudarshan Raj Tiwari, Tribhuvan University, Kathmandu, Nepal for helpful discussion on building typologies in Nepal;
- Bonisha Borah, a doctoral student at IIT Guwahati;
- Kishore Jha, Nepal Engineers' Association;
- Jason Ingham and Dymtro Dizhur, University of Auckland;
- Homraj Acharya, Global Fairness Institute;
- Laura Whitehurst, Walter P. Moore;
- Youb Raj Paudyal, Nepal Department of Education, and Ramesh Guragain, NSET for information on school retrofits; and
- Dr. Fred Krimgold, Director, Disaster Risk Reduction Program, Virginia Tech.

5.1 TYPICAL BUILDING TYPES IN NEPAL

The most common building typologies in Nepal are reinforced concrete (RC) frame buildings with masonry infill walls, unreinforced masonry (URM) bearing wall buildings, and wood frame buildings (Figure 5-1). The RC frames with masonry infills are commonly constructed in urban and semi-urban areas. Most of these buildings are three to five stories high, and most privately owned buildings are non-engineered. High rise buildings (up to 17 stories high) are also found in Kathmandu, but their number is limited. Burnt clay bricks are widely used as masonry infill walls; external walls are generally one full brick thick (~ 230 mm), and internal walls are one half brick thick. URM bearing wall buildings are an obvious choice for the population in rural areas and the outskirts of cities, primarily to limit the material expenses. Such buildings are generally two to four stories high and constructed using burnt clay brick masonry or stone masonry with cement, lime, or mud mortar. In some of the older constructions, a different mortar known as *Vajra* (a mix of lime and brick dust) is also observed. These buildings have either wooden or reinforced concrete flooring. A hybrid type of construction also prevails in semi-urban and rural areas, where wood frames are used in the ground story front façade, and rest of the house is made of unreinforced masonry bearing walls. Wood frame houses (generally two to three stories high) are also observed in rural areas where the material for such construction is easily available.

(a)

(b)

(c)

Figure 5-1. Common building typologies in Nepal: (a) masonry infilled RC frame buildings (photo: Hemant Kaushik), (b) URM bearing wall buildings (photo: Bret Lizundia), and (c) wood frame buildings (photo: John Bevington).

The three common types of construction in Nepal (i.e., masonry infilled RC frames, URM bearing wall buildings, and wood frame buildings) suffered a variety of damage during the 2015 Gorkhal Earthquake and aftershocks as described in Section 5.2. The RC frame buildings with masonry infills and URM wall buildings suffered extensive damage due to various reasons discussed in the following Sections 5.3 and 5.4. On the other hand, as expected, wood frame construction performed very well, except for those cases where slope failure took place or where the heavy brick veneer on the exterior collapsed, as discussed in Section 5.5.

5.2 BUILDING CODES AND BUILDING PRACTICE IN NEPAL

5.2.1 Nepal National Building Code

Building codes provide a set of regulations that govern the design, construction, alteration, and maintenance of a structure to increase safety of the occupants of that structure. Building code compliance is a key issue for any seismically active area, irrespective of whether it is from a developed or developing country. Codes have been under particularly close scrutiny in Nepal since the 2015 Gorkha Earthquake and aftershocks.

The Nepal National Building Code (NBC) (Government of Nepal, 1994) was established in 1994, following the M6.9 earthquake in 1988 that killed 721 people, particularly in the east of the country. Following the earthquake, an assessment of the seismic hazard of the entire country was carried out (Sharpe and Jury, 2000), with several provisions in the NBC being based on the level of hazard identified. Further provisions were based on design calculations referred to the Indian code of the time. Despite the extensive work involved to develop a code for Nepal, it took until 2004 for the NBC to be approved by the government with its adoption being made mandatory in 2006 for all government buildings and recommended for use in all municipalities. However, no deadline was set for the implementation of the NBC, a detail that has caused many issues since. It is widely known that the NBC has needed technical updating since its inception, because the adoption of the current version was intended only as a quick fix to establish a baseline building code instead of none at all (Bothara et al., 2000). A review of the NBC took place in 2009, and a draft of the new code was due for publication in mid-July 2015. Since the 2015 Gorkha Earthquake, the Department of Urban Development and Building Construction (DUDBC)—the responsible government department for formulation, updating, and implementation of building code in Nepal—has proposed some changes in the provisions under Mandatory Rules of Thumb (MRT) and Guidelines sections of the NBC. However, as of April 2016, no draft has yet been published, or had been made available to the project team.

The NBC is aimed at covering the typical and most common building types being constructed in Nepal. The NBC has a hierarchical structure, aligned with the sophistication of engineering input provided in the design or construction of a new building. Table 5-1 describes the main types of structures included in the NBC and the purpose for which they were designed.

The NBC is designed to act as a standard for guidance of the construction of new buildings; however, as discussed in the following sections, several technical limitations exist in addition to the low number of areas in it has been implemented. Finally, the NBC offers no guidance on retrofitting or improvement of existing owner-built structures, a limitation explored later in this section.

Table 5-1. Overview of the key elements of the Nepal National Building Code (UNCRD, 2008)

SN	Type of Building Code	Purpose
1	International State-of-Art Applicable codes: NBC 000	Applicable to large building structures. The structures must comply with existing international state-of-the-art building codes
2	Professionally Engineered Buildings Applicable codes: NBC 101, NBC 107, NBC 113 NBC 102, NBC 108, NBC 114 NBC 103, NBC 109, NBC 206 NBC 104, NBC 110, NBC 207 NBC 105, NBC 111, NBC 208 NBC 106, NBC 112	Buildings designed and constructed under supervision of engineers, buildings with plinth area more than 1,000 sq. ft., buildings having more than 3 stories, buildings with span more than 4.5 m and buildings with irregular shapes
3	Mandatory Rules of Thumb Applicable codes: NBC 201, NBC 202, NBC 205	Buildings of plinth area less than 1,000 sq. ft., less than 3 stories, buildings having span less than 4.5 m and regular buildings designed and constructed by technicians in the areas where professional engineers' service is not available
4	Guidelines of Remote Rural Buildings (Low Strength Masonry/ Earthen Buildings	Buildings constructed by local masons in remote areas and not more than 2 stories

5.2.2 Common Building Practices and Mandatory Rules of Thumb

The NBC focuses on improving the quality and safety of newly constructed buildings. However, a major problem facing Nepal is the high proportion of existing owner-built properties that do not comply with many of the provisions in the code. In urban areas, over 80% of all buildings are built by owners or local masons. This number increases to over 90% in rural areas (Dixit, 2009), and only about 5% of these have professional engineering design and supervision. In general, most of the owner-built structures are constructed following the advice of local craftsmen and masons. Figure 5-2 shows the breakdown of owner-built properties in Kathmandu Valley – the most developed region in Nepal. Although no official statistics could be found, it is highly likely that the proportion of owner-built properties in rural areas would be greater than those in Kathmandu Valley.

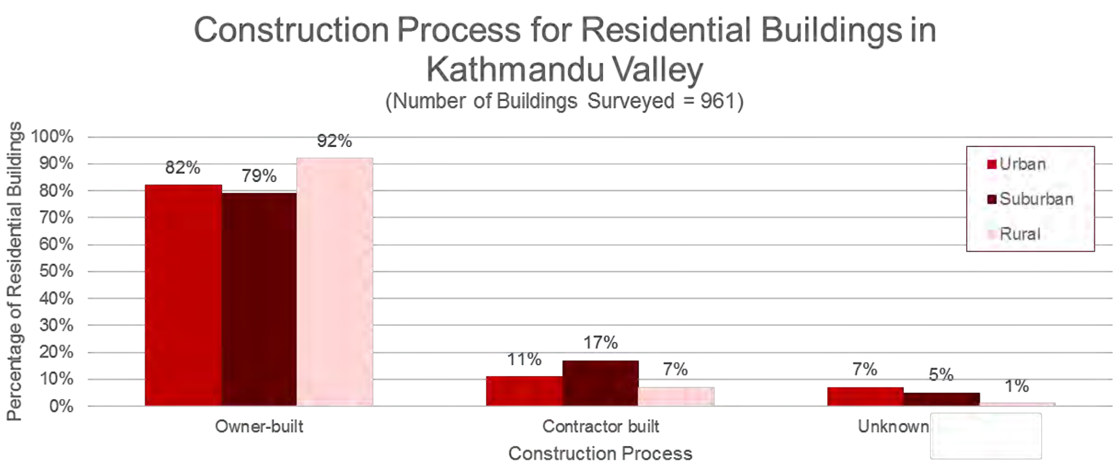

Figure 5-2. Breakdown of construction processes in Kathmandu Valley with data from a building inventory survey for the 2000 Study on Earthquake Disaster Mitigation of Kathmandu Valley (adapted from Dixit, 2009).

Since a significant portion of country's built stock is situated in remote areas and is being built with indigenous construction techniques, the NBC also provides guidance for seismically resistant construction of remote rural buildings, called the 'Guidelines.' The Guidelines were established to ensure that homeowners incorporate at least some standard design and detailing practices for rural houses. Likewise, standard design details have been recommended in the 'Mandatory Rules of Thumb – MRT' for most commonly available semi-urban to urban residential houses that use load bearing masonry walls and reinforced concrete frame with infill walls as the main structural system. The MRT and

Guidelines are prepared in the form of easy-to-understand and ready-to-use diagrams and descriptions of construction processes for the main building types that were surveyed in 1993 as part of the building code development process.

In many ways, the MRT are a success. They play an important role in providing a suitable and reasonable mechanism for governance, regulation, standards, and enforcement of non-engineered building stock. They also provide confidence to building owners and enable owners to move towards building code compliance.

Misuse of the MRT, however, is a common problem. For example, there is a lack of understanding about what types and sizes of buildings it can cover. Engineering design professionals inappropriately tend to use MRT provisions in professionally engineered buildings and sometimes try to apply provisions of the MRT to the other classes of buildings. Additionally, adoption, awareness, and use of the MRT by building owners and local masons in many cities is low, which results in haphazard construction practices and a building stock with inconsistent standards. Improved understanding about the purpose and appropriate uses for the MRT should continue to take place in Nepal, and several examples of this are described later in Section 5.2.4.

5.2.3 Technical Limitations and Recommendations

The Nepal NBC is over twenty years old and, while based on the Indian Code of the time (with adjustments for Nepal), now has several deficiencies which should be addressed in light of the Gorkha Earthquake and aftershocks. The seismic zoning scheme adopted within the NBC is largely based on seismic data and models that require further updating. The then Ministry of Physical Planning and Works of the Government of Nepal carried out a review of the NBC in association with the United Nations Development Program (Government of Nepal, 2009), identifying a wide range of technical and implementation issues. Some of these issues were explored further during the EERI reconnaissance trip and are discussed in the following subsections.

5.2.3.1 Seismic Hazards Zones and Site-specific Ground Motions

A seismic hazard zonation scheme underpins the seismic design requirements of the NBC (Sharpe and Jury, 2000), which ultimately get incorporated into professionally designed and engineered buildings in Nepal. Depending upon the location of a site, structural engineers make use of the NBC zoning factors applicable for a given location for earthquake resistant design. The current NBC zoning factors were based on a seismic hazard assessment carried out in 1994, and should be revisited and updated. Moreover, the site-specific earthquake resistant design and analysis is not required when the construction is regular and the building footprint area (the plinth area) is less than 1,000 square feet.

Additional attention should also be given to incorporate uncertainties associated with site-specific ground motion to provide an increased level of seismic safety. This fact was further underlined in a recent study on school safety that found as the design selection was based primarily on cost and not hazard exposure that meant that many of the recently built school buildings lacked sufficient seismic resistance (Paci-Green et al., 2015). Nepal has no dedicated requirements for school seismic safety set out in the NBC, unlike many countries where codes are more developed. Several efforts have sought to address this, such as the Manual for Designers and Builders, produced by NSET (Bothara et al, 2002), but it should be a future consideration for updating the NBC.

5.2.3.2 Structural Requirements for Reinforced Concrete (RC) Structures

There are a number of additional areas of recommended improvement to the NBC identified since the Gorkha Earthquake that could be applied to the predominant building type of RC structures. Revisions to the code should include clauses to define structural irregularity (both plan and horizontal) and describe design requirements that take these into consideration. Such improvements would aid the understanding and mitigation of soft story effects. The effects of infill masonry are poorly documented in the NBC, particularly specifics related to diagonal struts that form in the masonry infill and the impacts of struts on concrete frames. Additional information on concrete design such as cantilevered slab and prestressed concrete could be added learning from resources such as the International Building Code (IBC) and Eurocode. Inadequate seismic detailing within the RC elements of a building was a dominant causal factor behind many structural failures across Nepal. It has been noted since the earthquake that, in several school buildings, the infill walls lacked vertical or horizontal reinforcing steel to support them (Paci-Green et al., 2015). There is a high degree of detail provided in international codes, which would provide a useful reference to benchmark the detailing of steel reinforcement in all types of buildings, from urban to remote rural buildings. Education of construction designers and contractors clearly plays a vital role in this regard as well and is discussed in the Section 5.2.4.

5.2.3.3 Occupancy

In addition to site-specific seismic hazard considerations and improved structural requirements, certain occupancy types warrant additional design consideration. Performance-based design is used in many seismically-active countries in the developed world, and in some seismically prone developing countries, especially for critical facilities such as hospitals and schools, where higher safety margins are mandated and where the demand for shelter-in-place is great. Postearthquake usability of certain critical facilities should be at the heart of the future earthquake-resistant design standards in Nepal. For example, nonstructural elements such as interior supply lines, ceilings, partition walls, generators, and other utilities should have seismic design requirements for anchorage, bracing, and deformation compatibility to improve reliability and resilience. New housing should also be seismically resistant to offer shelter-in-place for building owners. Schools should be built or retrofitted to offer shelter-in-place for those with damaged homes. Additionally, consideration could be given to including provisions relating the number of occupants to exiting capacity and to seismic design requirements. In the 2015 International Building Code (ICC, 2014), for example, selected building uses with larger numbers of occupants take the building from the baseline Risk Category II to Risk Category III and thus to higher design requirements, including those for seismic design. Finally, the NBC is currently focused on new buildings and offers no consideration to changes in occupancy of existing buildings.

5.2.3.4 Geotechnical

The NBC does not take into consideration a number of geotechnical issues for which new guidelines are warranted. These issues include ground failure hazards (landslide, liquefaction, or lateral spreading), site-soil amplification, and provisions for buildings located on slopes. While liquefaction was observed in limited locations during the April and May earthquakes, it is still a hazard that requires professional guidelines during the revision of the NBC. Based on early findings from EERI reconnaissance mission, ridge top amplification was evident at number of locations, e.g., Chautara and other hilltop towns in Sindhupalchowk. Additional research focused on incorporating topography-induced amplification effects is needed in order to develop appropriate guidelines for inclusion in future building and design code documents.

5.2.3.5 Retrofitting

The postearthquake situation in Nepal calls for additional input from the broader engineering community for assistance and guidance in defining suitable repair and retrofitting strategies. This was a common need observed by the team when visiting moderately and severely damaged areas. Any future revision of the NBC should include guidance on repair and retrofitting as part of the main code or as “Dos and Don’ts” guideline documents and educational materials. Some efforts are ongoing specifically to address this, as outlined in the next section.

5.2.4 Adoption, Implementation, and Compliance Limitations

Alongside the technical adequacy of the Nepal National Building Code are the key issues of code adoption, implementation, and compliance. Although the NBC was published in 1994, implementation was not mandated until 2004. The municipality of Lalitpur, however, voluntarily adopted it in 2003, prior to the mandate.

A major issue undermining the success of the NBC is the fact that the building bylaws that are adopted by municipalities rarely include NBC safety or seismic-resistance provisions and therefore weaken the effectiveness of the code. The bylaws generally cover only provisions related to urban planning such as setbacks from road right-of-way, setbacks from property lines, building heights, etc. Even if the bylaws did include NBC provisions, there are still issues of implementation that challenge their effectiveness. Although the bylaws are meant to be followed throughout each municipality, the provisions are most commonly followed only in town centers and urbanizing or urbanized areas. Most rural areas do not follow the bylaws. This issue is currently under review, and it is essential that the building bylaws are made legally mandatory in order to close off any potential loopholes allowing rural construction practice to be outside the reach of the NBC.

Nepalese municipalities have the responsibility of adopting and implementing building codes, including the institution of compliance measures. Building permits for construction of new buildings are the main method used, with additional permits required for the vertical extension of structures. However, there appeared to be little evidence of full compliance to this requirement, especially in rural areas. As of April 2016, out of 217 municipalities in Nepal, the Department of Urban Development and Building Construction reports that 26 have adopted the NBC. In the postearthquake context, the capacity to enforce the NBC is realized to be very low compared to the level required for effective enforcement. The EERI reconnaissance team members came across numerous instances where the buildings were rebuilt the same way, without any formal supervision, and mostly by salvaging the clay and mud bricks from the damaged buildings (Figure 5-3). Although many of these were officially classed as “temporary” shelters, it is clear that many of these structures will be occupied for a long time and will eventually become part of the permanent built stock. Several news reports published one year after the earthquake have identified a lack of rebuilding since the earthquakes, particularly in the worst-affected rural areas, forcing communities to face a second monsoon in non-engineered, makeshift shelters (BBC, 2016). These reports were backed up by an inter-agency community perception survey in 14 districts, which found that 82 percent of respondents did not believe their main reconstruction needs have been addressed (Inter-agency Common Feedback Project, 2016). Provision of adequate technical supervision alongside financial assistance for affected communities is recommended.

Figure 5-3. Salvaging bricks from damaged and destroyed buildings in Bhaktapur (photo: John Bevington).

In several areas during the LFE mission, local residents demonstrated increased awareness of the vulnerability of existing damaged or dilapidated construction to future earthquakes. There were instances where homeowners requested to remove damaged upper portions of their homes or requested that a structural engineer check their neighbors’ poorly repaired or reconstructed houses. With the heightened public awareness and the fear from on-going aftershocks, there is currently a window of opportunity to further promote the deeper integration of building codes during the reconstruction phase in Nepal, particularly in the rural communities with low levels of code adoption to date.

Lack of compliance with available Mandatory Rules of Thumb (MRT) and other codes has led to extremely poor performance of large number of buildings in different regions of Nepal. For example, Figure 5-4 shows several cases of RC buildings damaged severely due to poor reinforcement detailing in RC members. Shear reinforcement provided in critical regions of columns of most of these buildings was in the form of 6 mm diameter bars at a spacing of 200 mm center-to-center with 90° hooks. By contrast, the requirement in the MRT is to provide 8 mm diameter bars in critical regions of columns at a spacing of 75-100 mm center-to-center with 135° hooks.

A number of positive activities promoting the adoption and implementation of building codes were also witnessed during the reconnaissance trip, both at the national level as well as at the local level. Many of these projects and programs have been administered through the National Society of Earthquake Technology – Nepal (NSET). One such project is the USAID / Office of U.S. Foreign Disaster Assistance (OFDA) funded Building Code Implementation Program (BCIPN) (NSET, 2015) being implemented by NSET. BCIPN is targeting 30 municipalities to develop local mechanisms to further advocate for and assist with code adoption and compliance by focusing on earthquake awareness, training, and capacity building. It is clear that there are very strong relationships between NSET and their implementing partners in the municipalities and Village Development Committees (VDCs). In Dolakha, after the earthquakes, the municipality office provided land to develop a Reconstruction Technology Center where local masons and engineers can receive training on safer construction and retrofitting technology. These activities build on ongoing public awareness efforts by NSET, including their regular mobile clinics and annual earthquake awareness day.

Figure 5-4. Poor reinforcement detailing led to collapse or severe damage to several RC buildings in Nepal (photos, annotations, and illustrations: Hemant Kaushik, unless noted otherwise): (a & b) Collapse of a three-story building at Chautara due to column failure, (c) buckling of longitudinal bars of columns in a four-story building at Balaju, and a four-story school building at Sankhu with (d) severe damage to beam-column joint, (e) rebar configuration and cross-sectional characteristics of the column observed on site, and (f) damage to column exposing rebar spacing (photo: Bret Lizundia).

5.2.5 Next Steps for the NBC

The Nepal National Building Code was developed following a significant earthquake, and was based on what was current thinking at the time. In the 22 years since the code was introduced, numerous challenges have been faced around building code awareness, adoption, implementation, and compliance. Yet despite this, a few municipalities have successfully and effectively implemented the NBC, with Lalitpur, Dharan at the forefront. Much attention is now focused on the NBC, not only in terms of implementation and compliance, but also in terms of technical adequacy. With increased pressure to revise the NBC, it is possible that the NBC will be updated in the near future, with a new draft currently overdue. Challenges still remain in terms of code adoption and compliance. However, a short window of opportunity now exists to capitalize on the heightened public awareness of seismic safety in construction. Public policy needs to be at the very core of seismic safety initiatives that are targeted not only at masons, but also homeowners and public officials—the very people commissioning construction projects.

The international earthquake engineering community has a role to play in assisting Nepal to develop basic guidelines for repair and retrofitting of damaged structures. Organizations such as NSET are already playing a lead role in increasing awareness through community-focused initiatives such as the earthquake safety day. It is hoped that as the memories of the 2015 earthquakes fade, the importance of ongoing awareness initiatives increases.

5.3 PERFORMANCE OF RC FRAME STRUCTURES WITH BRICK INFILL

RC frame buildings with masonry infill walls are commonly constructed in urban and semi-urban areas throughout Nepal. Most of the new government buildings and a large number of privately constructed new buildings fall into this category as there is a general perception that such buildings are much safer than the URM buildings. However, most privately built buildings are non-engineered and lack basic earthquake resistant features. Depending on functional requirements, low-rise, medium-rise, and high-rise buildings are all constructed as RC frame structures. RC frame buildings of all heights suffered damage ranging from minor to severe, and even to collapse, depending on their location and configuration (Figure 5-5).

(a)

(b)

(c)

Figure 5-5. Damage sustained by RC frame buildings with masonry infills with different heights: (a) three-story building in Chautara, (b) six-story building in Balaju, and (c) 17-story building in Dhapasi (photos: Hemant Kaushik).

Damage was more prominent in buildings constructed on ridge tops perhaps due to ridge-top shatter amplification of ground motion. Interestingly, masonry infill walls were found to be more or less intact in large number of buildings that had permanent displacement, implying a foundation failure (Figure 5-5a, 5-5b). Generally, a geotechnical investigation for the project site is not carried out in Nepal, except for some important projects, which often results in inappropriate foundations on slopes. A large number of buildings constructed on slopes collapsed or suffered permanent displacement/tilt due to foundation or slope failure (Figure 5-6).

Severe in-plane and out-of-plane damage was observed in masonry infill walls of RC frame buildings constructed on proper foundations (Figure 5-5c). These buildings dissipated a large amount of energy by cracking along both the in-plane and out-of-plane directions (Figure 5-7a). Similarly, severe damage was observed in long infill walls due to diagonal and shear sliding crack at mid-height in a school building at Sankhu (Figure 5-7b). As observed in several past earthquakes, such long walls are also quite susceptible to out-of-plane failure.

Figure 5-6. *Example of common hillside construction on precipitous slopes near Chautara showing use of weak rubble stone infill on the bottom base story of the building in the center of the image. The cause of failure of the collapsed building on the left is not known, but issues such as infill or lack of geotechnical input may have contributed to the failure of this building (photo: John Bevington).*

(a) (b)

Figure 5-7. *(a) Severe damage to infill walls along both in-plane and out-of-plane directions in the high-rise apartment building at Dhapasi, and (b) severe damage to infill walls due to diagonal and shear sliding crack at mid-height of walls in a school building at Sankhu (photos and annotations: Hemant Kaushik).*

Non-seismic reinforcement detailing in RC members was another important reason of poor performance for RC frame buildings. Poor design and detailing in combination with poor configuration resulted in 'pancake' style collapses, failure of beam-column joints, and shear failure of columns near door or window openings due to short column effects (Figure 5-4, 5-8, and 5-9).

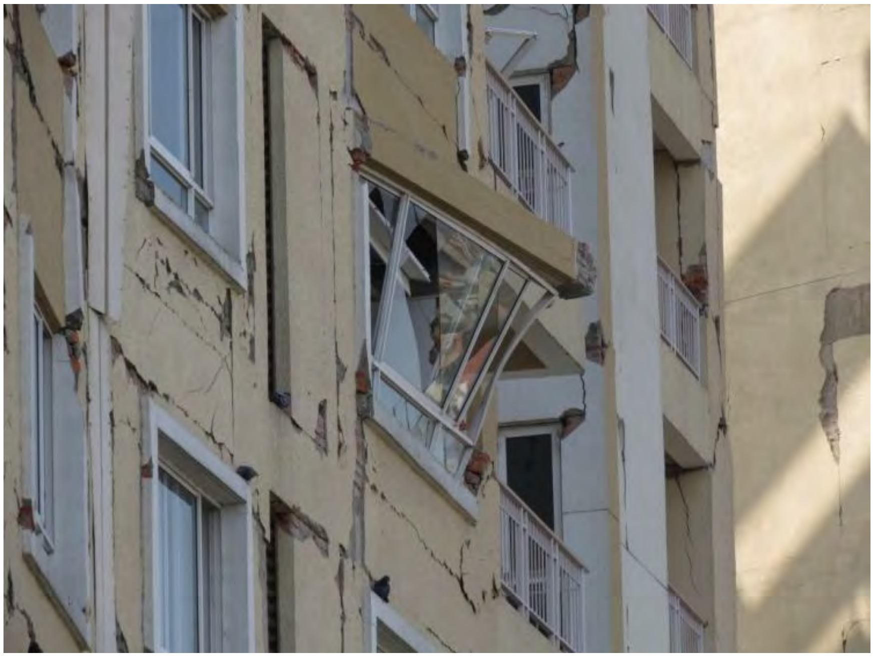

Figure 5-8. Poor seismic design and detailing in combination with poor geometric configuration resulted in severe damage in RC frame buildings with masonry infill walls, including the connection failure shown in the lintel of the 17-story Park View Horizon Apartments in Dhapasi (photo: Hemant Kaushik). Additional types of design and detailing failures are shown in Figure 5-4.

(a)

(b)

(c)

Figure 5-9. Poor seismic design and detailing in combination with poor geometric configuration resulted in severe damage in RC frame buildings with masonry infill walls: (a) collapse of a four-story building at Irkhu, (b), failure of beam-column joints in the same building, (c) rupture of reinforcing bars in first-story columns of the same building (photos and annotations: Hemant Kaushik).

Poor geometric configurations of buildings further reduced the seismic capacity and redundancy in many RC frame buildings resulting in poor performance. Large overhangs (progressive increase in floor area in upper stories by extending beams/walls beyond column grid lines), trapezoidal plan buildings with one end too narrow, floating columns, and soft stories were quite commonly observed in many buildings; this resulted in severe discontinuities in lateral stiffness, lateral load transfer path, and subsequent failure (Figure 5-10).

Poor quality of materials and workmanship are other considerations that reduced capacity and exacerbated damage to RC frame buildings, particularly in non-engineered RC construction. At various locations, it was observed that damage was a result of low-quality, non-engineered construction by laborers with insufficient skill, supervision, or both (Figure 5-11). Unplanned and unsupervised construction practice has also resulted in haphazard construction without sufficient gaps between buildings. Several buildings that were otherwise undamaged by earthquake shaking suffered severe damage due to pounding with adjacent buildings (Figure 5-12).

Severe ground failure and cracking in various areas also resulted in damage and failure of several buildings. For example, severe ground cracking and settlement was observed along the Araniko Highway at Lokanthali near Kathmandu. Several buildings sustained severe damage (mostly tilting of buildings due to foundation failure) on both sides of the highway (Figure 5-13).

Figure 5-10. Different types of geometric irregularities observed in RC frame buildings with masonry infills: (a) large overhangs in both directions at building in Sankhu, (b) trapezoidal plan building in Balaju, (c) large overhangs in one direction at building in Dhulikhel, (d) floating columns at a building in Chautara, and (e) soft story buildings in Lokanthali (photos and annotations: Hemant Kaushik).

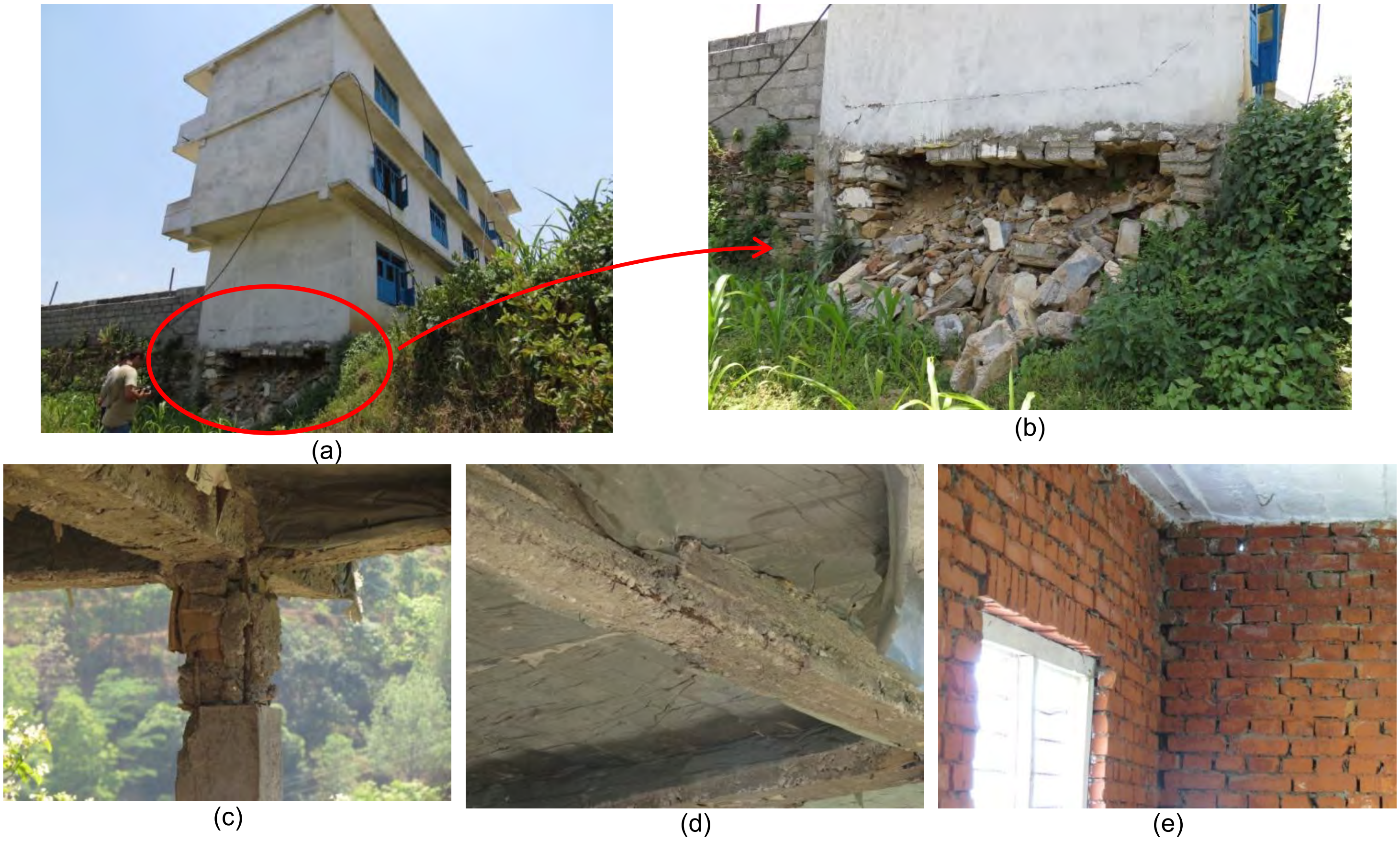

Figure 5-11. Poor quality of construction and workmanship further aggravated the problem: (a & b) poor quality of brickwork below plinth beam in a three-story building at Irkhu, (c) poor concrete quality in RC column and (d) RC beam in a two-story building at Dolalghat, and (e) poor masonry joints with absence of lintels over window opening in a school building at Dolalghat (photos and annotations: Hemant Kaushik).

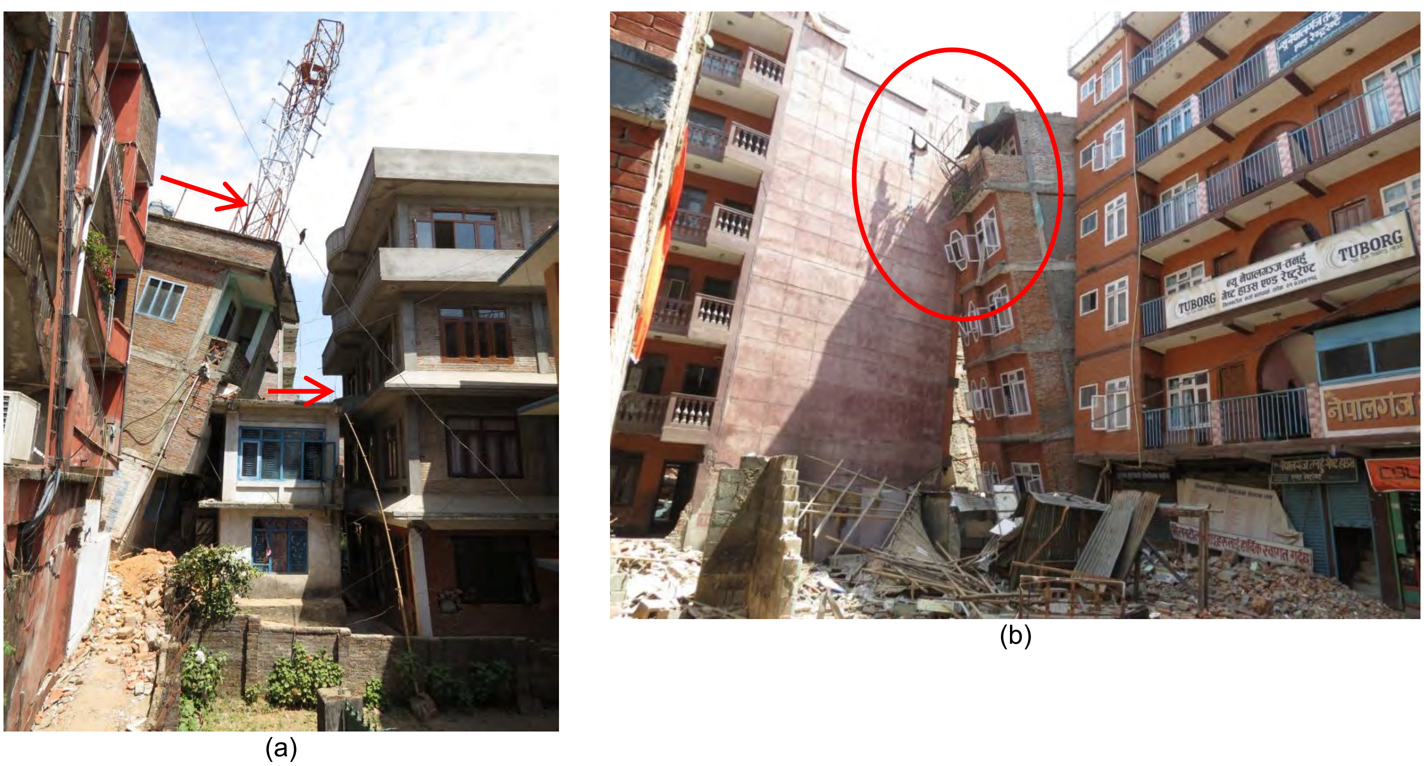

Figure 5-12. Pounding between adjacent buildings damaged buildings, which otherwise performed reasonably well: (a) a two-story house between two tilted buildings at Chautara, and (b) a six-story building suffered severe damage to tilting of an adjacent five-story building at Balaju (photos and annotations: Hemant Kaushik).

Figure 5-13. Several buildings on both sides of the Araniko Highway at Lokanthali near Kathmandu tilted due to foundation failure because of severe ground cracks and settlement (photos and annotations: Hemant Kaushik).

5.4 PERFORMANCE OF URM BEARING WALL STRUCTURES

Unreinforced masonry bearing (URM) wall buildings are the most widely used building typology in Nepal due to their lower construction cost when compared to RC frame buildings. URM buildings are commonly found throughout Nepal in both rural and urban areas. Generally, URM buildings are used for either entirely residential purposes or mixed-use purposes that have residential stories above a bottom story that is used for business purposes. The most typical height of URM buildings are two to three stories, with maximum of four stories occasionally found. In most cases, the geometry is regular (rectangular plan), and often a wood frame storefront is provided at the ground story to accommodate office/business space (Figures 5-14a and 5-14b), creating a soft and weak story. There is a common perception that URM buildings require less quality control and fewer engineering judgments, and hence, can be constructed by the owners themselves without involving engineers.

Walls in URM bearing wall buildings are typically made from brick masonry, stone masonry, or adobe using mud, lime, or cement mortar. Walls typically rest on either a brick or stone foundation. Roofing in these buildings primarily consists of corrugated galvanized iron sheets (CGI) or clay tiles (in valley areas) on wood joists, and the flooring is made by mud filling over wood sheathing supported on wood joists. In most cases, masonry wythes are poorly connected (Figure 5-14c) and the seismic features recommended for URM walls in seismic-prone regions (i.e. corner reinforcement, through stones, corner stones, intermediate bands, etc.) are missing (Bothara, 2011, Blondet et al., 2011). During the Gorkha

Earthquake, wythe delamination was observed in large number of URM buildings due to poor connection between wythes (Figure 5-15a). Figure 5-15b shows a parapet that collapsed, but in general relatively few parapets or masonry chimneys were observed by the reconnaissance team.

Damage observed in walls of URM buildings can be classified into two types: in-plane wall damage and out-of-plane wall damage. The in-plane wall damage was generally observed in the form of cracks in wall piers near openings as shown in Figure 5-16a and 5-16b. In some cases spandrel cracking and leaning were observed as shown in Figure 5-16c. As already discussed, seismic features (i.e. stone or concrete bands around openings) that are well known to reduce these types of damage in URM walls were not included.

(a) (b) (c)

Figure 5-14. (a & b) Typical URM bearing wall buildings in Nepal with wood frame store front in the ground story, and (c) brick wall and floor details in a typical URM bearing wall building at Banepa (photos: Hemant Kaushik).

(a)

(b)

Figure 5-15. (a) Delamination of wythes and partial collapse of exterior brick and mud mortar wall in Sankhu (photo: John Bevington) and (b) collapse of unsupported stone and mud mortar parapet wall in Dolakha (photo: Bret Lizundia).

(a)

(b)

(c)

Figure 5-16. (a) In-plane wall damage in Gangabu (photo: Hemant Kaushik), (b) in-plane damage to wall pier in Gangabu (photo: Bret Lizundia), and (c) in-plane spandrel cracking and ground story leaning in Dhulikhel (photo: Hemant Kaushik with annotations by Bret Lizundia).

Out-of-plane damage was observed in large number of URM bearing wall buildings primarily due to poor diaphragm-to-wall ties, inadequate out-of-plane wall capacity, and initial in-plane damage (Figure 5-17). Collapse of such walls in the out-of-plane direction resulted in large loss to life and property during the Gorkha Earthquake. People also reported that smaller adjacent buildings suffered heavy damage due to out-of-plane collapse of walls in adjacent taller buildings. People were seen collecting the bricks and stones from the fallen walls and cleaning them for future construction (Figure 5-3). Although, some government and non-government organizations were providing suggestions on better construction practices, urgency to reconstruct houses before the approaching monsoon season was resulting in construction by many people using the same traditional practices without incorporating any seismic strengthening features.

Corner damage was also quite commonly observed at the intersection of roof and walls subjected to in-plane and out-of-plane demands (Figure 5-18). Corner damage and subsequent collapse of the walls often took place due to poor connection between the floor or roof diaphragms and the walls, and between perpendicular walls. Subsequent to failure and collapse of walls in the top story of URM buildings, severe damage to roof or attic framing was also observed, as shown in Figure 5-19.

A combination of in-plane and out-of-plane damage in URM bearing wall buildings contributed to the complete collapse of many buildings in Nepal both in urban as well as rural areas (Figure 5-20). Though statistical data are not available, the reconnaissance team observed that the buildings constructed with mud mortar suffered more significant damage than those constructed using cement or lime mortar.

(a)

(b)

(c)

Figure 5-17. Out-of-plane collapse of (a & b) brick masonry walls at Bhaktapur (photos: Bret Lizundia) and (c) stone masonry walls in Dolakha district (photo: John Bevington).

(a)

(b)

Figure 5-18. Corner damage in brick masonry walls at (a) Dolakha district (photo: John Bevington), and (b) Banepa (photo: Bret Lizundia).

(a)

(b)

Figure 5-19. Roof or attic damage in stone masonry buildings in Dolakha district (photos: John Bevington).

(a)

(b)

Figure 5-20. Partial and complete collapse of stone masonry buildings in (a) Chautara (photo: Jan Kupec) and (b) Sankhu (photo: Bret Lizundia).

In summary, URM buildings performed worse than RC frame with masonry infill. Moreover, buildings with poor quality construction and mud mortar performed noticeably worse. Typical damage to these buildings includes wythe delamination, out-of-plane/in-plane/corner wall damage, roof/attic damage, and partial/total collapse. Due to the extensive losses from URM building damage, significant rebuilding of housing is needed. In addition, repair/strengthening standards are immediately needed to assist with reconstruction and restoration activities.

5.5 PERFORMANCE OF WOODFRAME STRUCTURES

Although the construction of timber frame houses has been in practice for centuries in Nepal, this construction style is highly dependent upon availability of good quality of timber, and the availability of skilled manpower. These factors ultimately dictate their performance during earthquake shaking. With the rapid growth of population, availability of limited construction space, and lack of availability of timber to meet the construction demands, the traditional timber frame construction practice has been diminishing for decades. The existing timber frame building stock represents less than five percent of built stock in urban areas and less than 10% of dwellings in rural areas.

While there are many variants of timber frame construction, three broad categories were impacted by the Gorkha Earthquake sequence and witnessed throughout the Kathmandu Valley and neighboring regions: (1) traditional heavy post-and-beam timber frame with infill masonry walls as shown in Figure 5-21, (2) post-and-beam timber frames made using light sheathing material (often CGI) for roof and walls as shown in Figure 5-22, and (3) Load-bearing timber frame walls with bamboo/reed (wattle and daub) as shown in Figure 5-23. The traditional heavy timber framing construction is widespread in the historical urban centers of Nepal whereas the simple post-and-beam light timber frame with CGI or other sheathing materials primarily occurs in the rural areas of Nepal.

Due to the lightweight construction and inherent ductility in the framing system, timber frame houses performed reasonably well during the earthquake and aftershocks when compared with the URM bearing wall and RC frame dwellings. Despite the fact that this construction type represented only a small fraction of total housing stock, many local community members in regions visited by the reconnaissance team noted its good performance. Given the strong aftershocks, the EERI team observed that many local masons and homeowners had started building temporary shelters in the form of a single-story light timber frame house.

(a) (b)

Figure 5-21. Traditional heavy post-and-beam timber frame buildings with infill masonry walls showing damage to masonry and timber elements (photos: Kishor Jaiswal).

Figure 5-22. Examples of post-and-beam timber frames with light metal sheathing for roof and wall in (a) urban areas and (b) rural areas (photos: Kishor Jaiswal), and (c) when used for temporary housing (photo: John Bevington).

Figure 5-23. Load-bearing timber frame walls with bamboo/reed wattle and daub wall construction in Dolakha district (photos: Kishor Jaiswal).

5.6 REGIONAL DIFFERENCES

The three most common building typologies in Nepal described in this report (RC frame buildings with masonry infill walls, URM bearing wall buildings, and wood frame buildings) are also commonly found in neighboring countries including India, China, Pakistan, Bangladesh, Bhutan, and Myanmar. In fact, large quantities of construction equipment, materials, and labor used in building construction in Nepal are procured from India. Therefore, a lot of similarity exists in the construction techniques, building typologies, design methods, and performance of such structures observed during past earthquakes

(Kaushik, 2013; Kaushik et al., 2006; Kaushik, 2007; Arlekar et al., 2002a; Arlekar et al., 2002b; Dash et al., 2006; and Murty, 2006).

For example, RC frame buildings with masonry infill walls are the most preferred type of construction in urban and semi-urban areas of most of the countries in the region. In most cases, lightweight concrete bricks or burnt clay bricks with cement mortar is used in constructing masonry infill walls. In past several earthquakes, such buildings constructed on slopes have performed extremely poorly in hilly regions of India (Kaushik, 2013). Masonry infilled RC frame buildings with irregular configuration are also some of the worst performing buildings during past earthquakes in different countries, similar to what was observed during the 2015 Gorkha Earthquake.

Similarly, URM bearing wall buildings constructed using undressed stones and mud mortar have suffered severe damage during past earthquakes in India, Pakistan, and China. URM bearing wall buildings are commonly constructed in both rural and semi-urban parts of the countries, and mud mortar is used in large number of cases. In addition to undressed stones, burnt clay bricks are also used in construction of URM buildings without involving engineering services.

Historically, it has been observed that the wood frame buildings perform very well during earthquakes, and the trend has continued during the 2015 Gorkha Earthquake. A large variation exists in type of wood construction practice in the neighboring countries, but mostly the variation is in the wall construction (Murty, 2006). In most cases, the primary lateral force-resisting system consists of wooden posts and joists supported by masonry walls or pillars. Local people have used several different types of wall materials in such houses depending on the availability of material, environmental conditions, and historical construction practices. Despite these variations, most of these houses have performed well during past several earthquakes.

5.7 CHAUTARA SURVEY

Earthquake reconnaissance efforts generally do not have sufficient time or resources to collect statistical damage data, and instead observations and findings are typically based on an anecdotal approach. In Chautara, however, the EERI team had sufficient time to conduct a detailed statistical survey of the damage to all of the buildings along each side of a long, representative length of the main town street, also known as the Dolaghat-Chautara Highway. This was a unique opportunity. Damage was significant in Chautara and along the street. The street was near or at the crest of the hill, and some of the buildings were on the up slope side of the hill, while others were on the down slope side of the hill. Postearthquake safety evaluations had been done along this street prior to the EERI team's visit, and they were documented with a red, yellow, or green spray painted dot on the buildings to represent their UNSAFE, RESTRICTED USE, and INSPECTED status. See Chapter 8 for more details on postearthquake safety evaluations.

Information was recorded for 152 buildings by a group of four EERI team members who reached consensus on each building. The evaluation began at Press Chowk Square at 27.7734ºN, 85.71699ºE and proceeded north to 27.77733ºN, 85.71201ºE to the informal United Nations settlement camp. Buildings on the up slope side of the street where typically on relatively flat site. Those on the down slope side had a relatively steep drop off to the rear of the building. Figure 5-24a shows the rear of a building on a steep down slope. Figure 5-24b shows the postearthquake safety evaluation marks for a pair of buildings.

At the time of the EERI visit, not all of the buildings had the spray painted mark visible. Some were so badly damaged that they had been demolished or were in the process of being demolished. Others had collapsed, but were not yet demolished. For those with lesser levels of damage, the ATC-13 (ATC, 1985) damage scale was used, with qualitative damage state categories of major, heavy, moderate, slight, light, and none. All of the buildings along the street were either URM bearing wall buildings or reinforced concrete frame with masonry infill. There were 56 URM buildings and 96 RC frame buildings. Of the URM buildings, 46 were stone, four were brick, and six were a combination of stone and brick.

Table 5-2 provides a summary of all 152 cases showing the damage status, building type, and slope condition. Table 5-3 combines the more severe damage status categories of demolished, collapsed, major, red and heavy into one group and the less severe categories of yellow, moderate, green, slight, light, and none into a second group, and then provides the percentages for each group. The following observations can be made from Table 5-3.

- RC frame buildings performed better than URM buildings. For the RC frame buildings, 47% were in the more severe damage category; for URM buildings, 89% were in the more severe category.

- Buildings on flat lots on the up slope side of the street performed better than those on the down slope side of the street. For flat lots, 54% were in the more severe damage category; for down slope lots, 66% were in the more severe category.
- URM buildings on the down slope side of the street performed particularly poorly, with 97% in the more severe damage category.

(a)

(b)

Figure 5-24. (a) Rear view of RC frame with masonry infill building in Chautara showing the down slope side (photo: Bret Lizundia, and (b) damaged buildings in Chautara showing spray-painted marks indicating postearthquake safety evaluation status (photo: Hemant Kaushik with annotations by Bret Lizundia).

Table 5-2. Chautara street survey showing number of buildings by damage status, building type and slope condition

	Number of Buildings by Structural Type and Slope Condition								
	All Buildings			URM			RC Infill		
Damage Status	Flat or Down	Flat	Down	Flat or Down	Flat	Down	Flat or Down	Flat	Down
Demolished	20	2	18	20	2	18	0	0	0
Collapsed	10	5	5	9	5	4	1	0	1
Major	2	0	2	0	0	0	2	0	2
Red	58	17	41	18	7	11	40	10	30
Heavy	5	2	3	3	2	1	2	0	2
Yellow	33	8	25	1	1	0	32	7	25
Moderate	4	2	2	1	1	0	3	1	2
Green	9	3	6	1	0	1	8	3	5
Light	4	4	0	1	1	0	3	3	0
Slight	6	4	2	2	2	0	4	2	2
None	1	1	0	0	0	0	1	1	0
Total	152	48	104	56	21	35	96	27	69

Table 5-3. Chautara street survey showing percentage of buildings by damage status, building type and slope condition

	Percentage of Buildings by Structural Type and Slope Condition								
	All Buildings			URM			RC Infill		
Damage Status	Flat or Down	Flat	Down	Flat or Down	Flat	Down	Flat or Down	Flat	Down
Demolished/Collapsed/Major Red/Heavy	63	54	66	89	76	97	47	37	51
Yellow/Moderate/Green Light/Slight/None	38	46	34	11	24	3	53	63	49
Total	100	100	100	100	100	100	100	100	100

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CHAPTER 6
HOSPITALS, SCHOOLS, NONSTRUCTURAL HAZARDS, AND MITIGATION PROGRAMS

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Acknowledgements:
We would like to thank the following individuals and organizations: Youb Raj Paudyal, Nepal Department of Education, and Ramesh Guragain, NSET, for information on and tours of retrofitted schools; and Sunil Khadka, Nepal Ministry of Health and Population, and Hima Shrestha, NSET, who were an integral part of our healthcare evaluation team; directors, facilities managers, and staff at the hospitals and the Ministry of Health and Population for their generosity in sharing their personal and organizational experiences, providing supporting data, and guiding our team on detailed tours of their facilities.

This chapter provides observations of damage to hospitals, schools, and nonstructural elements, reviews school retrofit programs and approaches, and discusses nonstructural hazard mitigation efforts. Recommendations to achieve improved earthquake performance are provided.

6.1 HOSPITAL PERFORMANCE AND PREPAREDNESS

The timing of the earthquake helped minimize the casualties of the disaster, but even so, nearly 9,000 people lost their lives and more than 22,000 were injured due to the earthquake. The World Health Organization's Global Health Cluster Report indicates that of those lost and injured, 18 and 68 were health workers, respectively (WHO, 2015). With these human impacts, there were high demands on the healthcare system. Again, the Ministry of Health and Population reports that out of the 4,118 public and 350 private health facilities that they oversee, 462 were completely damaged, 765 were partially damaged, and the losses are expected to surpass $63 million US dollars. Additionally, the World Health Organization performed a rapid health assessment of hospitals and healthcare facilities in 12 affected districts in Nepal at the time of the EERI reconnaissance trip, and found that approximately 90 percent of health care facilities outside main towns were not functioning. The assessment included 21 hospitals in 10 districts (nine private hospitals, eight district hospitals, and four larger central hospitals). Of these, four district hospitals (Chautara Hospital, Ramechhap District Hospital, Rasuwa District Hospital, Trisuli District Hospital) were not functional, with damaged infrastructure (no water supply or power, and perhaps only limited out-patient activities). These four district hospitals were replaced by field hospitals that were managed by foreign medical teams. Hospitals in Kathmandu Valley experienced varying degrees of damage, with many red-tagged structures but no catastrophic failures. Many evacuated all patients but were able to maintain a significant portion of their health care services in alternative spaces (e.g., mobile health camps, field hospitals, etc.) in the immediate aftermath of the earthquake. Long-term impacts are still unknown, but assessments by the EERI team, as well as initial reports from the Ministry of Health and Population, indicate that continuity of care in the valley was possible due to creative interventions by healthcare workers, international disaster relief efforts, an enormous (hundreds of thousands of people) outmigration of residents in the valley, the resilience of the healthcare system created by a need to be self reliant before the event, and due to recent activities in disaster preparedness (i.e., staff training at the hospitals).

Kathmandu's hospital network is composed of a heterogeneous building stock: most buildings do not comply with any seismic code provisions while others are constructed by using seismic provisions from international donors (e.g., Japan, China, and India). Many of Kathmandu's hospital buildings share structural similarities with older concrete hospital buildings in the U.S. Of the functional hospitals (e.g., Kanti Children's Hospital and Paropakar Maternity and Women's Hospital), many are struggling to manage a large number of patients given their damaged infrastructure, limited materials and medical supplies and essential medicines were likewise proving challenging. Although critical physical infrastructure was crippled and important supply chains were severed, the human healthcare infrastructure was able to adequately provide services to address immediate healthcare needs.

In order to understand the loss of capacity of individual healthcare facilities in the Nepal disaster, the EERI team collected data that describes the baseline functioning of each facility, the physical damage to the facility caused by the hazard event, and the functional impact that damage had on clinical and nonclinical areas immediately after the event. The survey instrument was tested and validated following several earthquakes (Kirsch et al., 2011, Mitrani-Reiser et al., 2012). The team used the pre-event data and first-hand experience with Nepal's built environment and healthcare system to customize a survey instrument before deploying to the field. The instrument used for Nepal captures baseline physical in-patient capacity (i.e., number of beds, discharges, etc. by service type), out-patient capacity, staffing information, baseline utility and backup assessment, structural and nonstructural damage assessment, loss of function by service area (and reason for loss by physical damage), supply chain impact assessment, and disaster response activities (including staff reporting, patient surge, patient evacuation and transfers, and supply demands).

6.1.1 Site Visits

During the EERI reconnaissance field mission, our team visited six hospitals in the Kathmandu District, five of them public and one private facility. The locations of hospitals and health posts visited by the team are shown in Figure 6-1. This figure also shows the location of the epicenter of the main shock, plus locations of strong aftershocks, as well as the area where strong shaking was felt. The hospitals visited by the team include: Bir Hospital, Tribhuvan University Teaching Hospital (TUTH), Kanti Children's Hospital (Figure 6-2c), Paropakar Maternity and Women's Hospital (Figure 6-2d), Nepal Medical College and Teaching Hospital, and Grande Hospital. We also drove to the Gorkha District, to assess health care impact closer to the epicenter of the main event. In the Gorkha District, we visited the district hospital (Figure 6-2a and b), Benighat Health Post, and one primary health center.

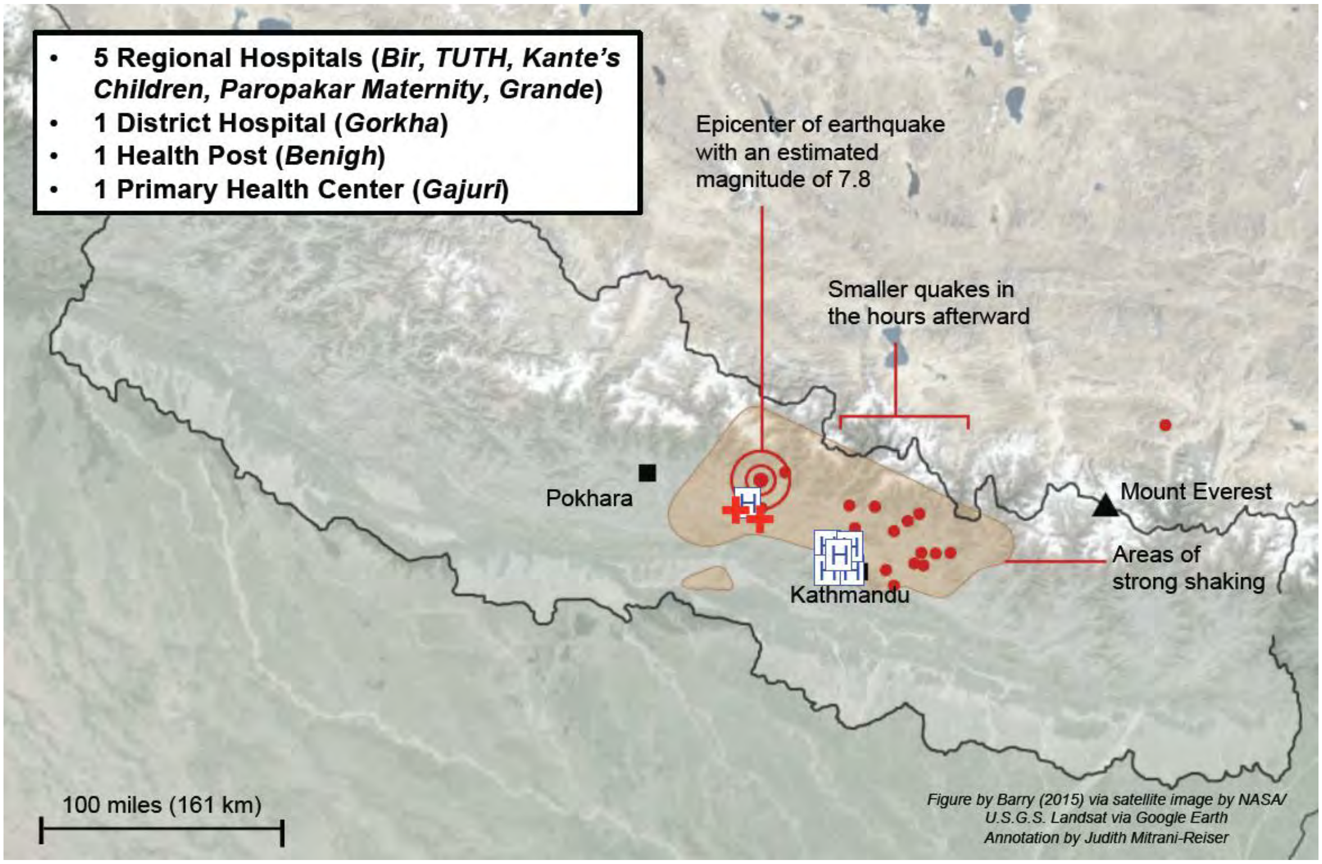


Figure 6-1. The locations of the six hospitals (square with the letter 'H'), health post (red cross), and primary health post (red cross) visited by the team. The sites of the hospitals are overlaid on a map showing the epicenter of the first event, aftershock locations, and the area where strong shaking was felt.

Figure 6-2. (a) Gorkha District Hospital Block 'H' was closed after the earthquake, (b) Gorkha District Hospital Block 'B' has a simple plan and did not suffer any structural damage, (c) patients crowded in the lobby at Kanti Children's Hospital six weeks after the earthquake, and (d) field hospitals and displaced medical equipment outside a red-tagged structure at Paropakar Maternity and Women's Hospital (photos: Judith Mitrani-Reiser).

6.1.2 Performance of Healthcare Facilities

Out of all the healthcare facilities that were visited, all suffered nonstructural damage, and some suffered structural damage resulting in natural closures (collapse or severe damage) and forcible closures (red tags). All of the facilities, except one, have their own supplies for power and water and so used their backup supplies to manage disruptions immediately following the earthquake. All of the hospitals (i.e., not the health post nor the primary care center) evacuated most or all of their patients within one hour of the earthquake; many hospital services moved into temporary medical tents brought in by other governments, NGOs, and the Ministry. These tents along with normal reporting by clinical staff and a manageable patient surge (due to a large outmigration from Kathmandu into more rural areas) allowed all facilities to continue operating, without shutting down, after the earthquake.

6.1.3 Performance of Utility Lifelines

Chapter 4 outlines in detail the earthquake's impact on critical utilities. The reported lifeline impacts to healthcare facilities covered a wide range of performance of their municipal power service: the two health posts reported no significant loss, two hospitals (TUTH and Kanti) in Kathmandu reported a few hours of loss, four hospitals reported a few days of power loss (Bir, Grande, Paropakar, and Gorkha Distrct), and one hospital reported a more significant power loss of one week (Nepal Medical College). Although all the healthcare facilities suffered some form of loss in the municipal power, all of them are accustomed to having municipal power shut off for part of their day. Given the daily necessity for backup power generation, the facilities all test/use their backup power supplies (diesel generators and solar panels) on a daily basis. This daily use of backup power generation proved helpful, as most facilities reported no disruption in using their backup power supplies strategically (e.g., during evening hours and during critical hours in the daytime). Only one facility (Paropakar) reported having trouble with their generator for one hour after the earthquake, and a few hospitals reported not having sufficient fuel onsite (Figure 6-3b) but quickly found ways to get fuel onsite. Additionally, most of the generators at the visited sites were not anchored (Figure 6-3a), but we saw no damage to them probably due to the limited ground shaking felt at these facilities.

(a)

(b)

Figure 6-3. (a) Example of unanchored backup power generator at a healthcare facility; and (b) fuel storage for a backup generator that barely supplies six hours of power for the healthcare facility (photos: Hari Kumar).

The interviews made clear that there was little dependence on municipal water sources for daily operations in the healthcare facilities; only two facilities largely depended on municipal water supply. Most of the healthcare facilities had a single (e.g., Bir Hospital in Figure 6-4a) or multiple boreholes (TUTH), as well as water storage tanks (above and below ground) on site for daily consumption. Of all the facilities visited, one reported minor pipe damage (Kanti), and another (Paropakar) reported a contamination issue with the water from their borehole turning brown/black. A third facility (Nepal Medical College) largely dependent on municipal water lost this water source for four days, but they were able to manage with their own backup water storage tanks for the first 48 hours after the earthquake and with the additional water tankers brought in afterward. The team observed several seismic mitigation actions taken by the healthcare facilities on their water systems, including multiple boreholes per site, power generators dedicated specifically to pumps for water distribution (TUTH in Figure 6-4b), anchorage of water tanks (Kanti Hospital in Figure 6-28a), flexible joints of pipes (TUTH Figure 6-29a), and pre-existing agreements with private or public institutions to bring in water tankers if their backups failed. The amount of stored water on each campus and the level of mitigation actions taken (i.e., Figures 6-4b, 6-28a, and 6-29) were inconsistent. All of the facilities were also asked about any disruption to their communication system, including landlines, internal communication channels, and cellular connection. All of the healthcare facilities reported issues with all forms of communication in the first few hours after the earthquake due to overloaded networks.

(a)

(b)

Figure 6-4. (a) A single water source, from a borehole, for an entire hospital campus (Bir); and (b) backup generators for water pumps at TUTH (photos: Judith Mitrani-Reiser and Hari Kumar).

6.1.4 Performance of Medical Gases and Equipment

Of all the visited facilities, several (Bir and Kanti) reported unbraced medical gas tanks falling over and scaring occupants (Figure 6-5a), and there were also few reports of damage to radiological machines (e.g., Figure 6-5b at Nepal Medical College) and autoclaves. The damage to equipment that was most disruptive to daily operations were the falling medical gas tanks, not because of any loss to the oxygen supply but because of the loud noises resulting from the tanks falling over and making occupants fearful of being indoors.

(a)

(b)

Figure 6-5. (a) Example of oxygen tanks fallen over at Kanti Children's Hospital, and (b) a damaged x-ray machine at Nepal medical College (photos: Hari Kumar).

6.1.5 Performance of Clinical and Support Staff

All the healthcare facilities were asked to report on their staff's ability to report to work given their personal lives being severely impacted by the earthquake. All the healthcare facilities, except two (Bir Hospital and Grande Hospital), reported normal or above normal numbers of their physicians, nurses, and other clinical staff in the first week after the earthquake, and normal reporting there after. Most hospitals reported lower than normal attendance of their administrative, clerical, and other support staff in the first 24 hours after the earthquake; two facilities (Nepal Medical College and Grande) suffered a one-week loss of this type of staff support. Most of the hospitals and the health post provide housing onsite for doctors, nurses, and technicians, facilitating quick reporting after the earthquake. However, structural damage was observed to nursing quarters at Ghorka's District Hospital, displacing them to tents, as shown in Figure 6-6.

Figure 6-6. Example of damage to staff living quarters at Ghorka District Hospital (photo: Hari Kumar).

6.2 PERFORMANCE OF SCHOOL BUILDINGS

6.2.1 Overall Performance of School Buildings

Altogether more than 6,000 school buildings suffered various levels of damage during the earthquake (NPC, 2015). Per the Department of Education (DOE), 59 educational districts were impacted by the earthquake of which 31 educational districts indicated severe damage. There were 23,158 schools in these districts serving 5,400,000 students. Out of 257,800 classrooms in these schools, 22,400 classrooms suffered total collapse and another 33,000 experienced major damage.

School building damage was assessed based on the postearthquake safety evaluation process developed by NSET and Department of Urban Planning and Building Construction (DUDBC), which assigns five "Damage Grades" from DG 1 to

DG 5 (discussed in more detail in Chapter 8, Section 8.3). Approximately, 6,000 school buildings received a damage score of either DG 4 or DG 5, which indicates collapse. Another 11,000 school buildings had heavy damage as indicated by their damage scores of DG 2 or DG 3.

There are three primary types of school buildings prevailing in the earthquake-affected areas. The performance and damage patterns of each building type are briefly described in the following paragraphs and figures.

1. Unreinforced masonry buildings (stone, brick or adobe) with cement or mud mortar
2. Steel frame with masonry infill walls
3. Reinforced concrete frame with masonry infill walls

Unreinforced masonry buildings are common with construction typically either stone or bricks in mud mortar or cement mortar. The majority of stone school buildings with cement mortar suffered heavy damage (DG 3 to DG 5). The main failure patterns seen were out-of-plane wall failure, tilting, in-plane diagonal cracking, collapse of gable walls at roof level, corner separation, and diagonal cracking around window or door openings. Examples of damage to these types of structures are shown in Figure 6-7. The main cause for these failures was poor construction quality, lack of seismic bands, lack of corner strengthening, and poor building maintenance.

(a)

(b)

Figure 6-7. Examples of damaged school buildings with stone and cement mortar: (a) damaged school in Gorkha, and (b) school in Chundevi, Kathmandu assessed as Damage Grade 3 (photos: NSET, 2015).

Examples of schools with mud mortar are shown in Figures 6-8 and 6-9. Most of these buildings suffered full collapse or were so heavily damaged that they cannot be repaired. Almost 60% of school buildings made with stones and mud mortar collapsed.

(a)

(b)

(c)

Figure 6-8. Examples of damaged school buildings with brick and mud mortar: (a) Rupak Memorial School in Sanepa assessed as Damage Grade 4, (b) adjacent building fell on Mahendra Lower Secondary School building in Bhaktapur assessed as Damage Grade 3, and (c) Padma Higher Secondary School in Bhaktapur assessed as Damage Grade 4 (photos: NSET, 2015).

Figure 6-9. *Examples of collapsed school buildings with stone and mud mortar: (a) Collapsed school with large opening, (b) failure of wall from corner in Gorkha district, (c) damaged school, and (d) Sarada School in Sindhupalchowk with weak stone masonry in mud mortar without any bands or through stones, assessed as Damage Grade 4 (photos: NSET, 2015).*

Most of the school buildings with steel frames and masonry infill walls were damaged due to failure of the infill walls. In most cases, no proper connection between the infill and steel structural elements existed; thus, while the frame was found intact, the masonry walls collapsed. Many of these buildings were affected by infill collapse, as shown in Figure 6-10.

(a) (b) (c) (d)

Figure 6-10. Examples of damaged school buildings with steel frames and masonry infill: (a) Ram Lower Secondary School in Sindhupalchok assessed as Damage Grade 4, (b) collapsed school building in Manohara municipality, Kathmandu assessed as Damage Grade 5, (c) school where wall survived due to horizontal band at sill and lintel level even after falling of bricks from the middle of the wall, assessed as Damage Grade 2, and (d) isolated wall piers not integrated with steel frame that were heavily damaged during earthquake shaking at Kalika Secondary School in Nagarkot, assessed as Damage Grade 3 (photos: NSET, 2015).

The majority of the RC frame school buildings were found undamaged or only suffered minor damage, although there were exceptions where schools were heavily damaged (notably some high rise private school buildings suffered pancake collapse in Kathamandu). Examples of modestly damaged RC frame structures are shown in Figure 6-11. In cases where damaged occurred, it was most frequently found in the infill walls and beam column joints. Several reasons for these failures can be assumed, including inadequate design, construction that did not follow the building code, deficient structural elements, poor detailing, poor construction quality, and poor maintenance.

(a)

(b)

(c)

Figure 6-11. Examples of damaged school buildings with RC frames and masonry infill: (a) Okharpauwa Secondary School in Okharpauwa assessed as Damage Grade 3, (b) damaged school in Gorkha, and (c) damaged school in Nuwakot (photos: NSET, 2015).

Nonstructural damage was also common in schools with typical examples shown in Figure 6-12.

(a) (b)

Figure 6-12. Examples of nonstructural school damage: (a) Fallen single desks and benches are scattered amongst standing desks in a classroom at Buddha Jyoti School in Kathmandu, assessed as Damage Grade 1, and (b) Spalling and cracking at column in Gokarna Higher Secondary School in Kathmandu, assessed as Damage Grade 1 (Photo: NSET, 2015).

6.2.2 Performance of Retrofitted School Buildings

The National Society for Earthquake Technology – Nepal (NSET) initiated a school retrofitting program in 1997 with the technical support from GeoHazards International (GHI), a US non-profit. Since then, NSET, together with several other government agencies, non-government organizations, and international development partners, has retrofitted more than 300 school buildings throughout the country (NSET, 2014). The type of school buildings ranged from unreinforced adobe buildings to mud-mortared brick and stone masonry bearing wall buildings to reinforced concrete frame with infill masonry wall buildings.

The School Earthquake Safety Program (SESP) is a holistic approach taken by NSET to improve the earthquake safety of communities by intervening in schools. Building earthquake-resistant communities through intervention at schools is at the core of SESP. SESP helps to make schools safer against earthquakes through the seismic strengthening of school buildings; training school teachers, students, and parents on earthquake safety; and enhancing earthquake preparedness of schools (Figure 6-13). It also focuses on making communities safer by propagating the knowledge from schools to the communities, and training local masons on safer construction practice (NSET, 2014). Consultants do the program work, and a plan check of engineer's drawings/calculations is always performed. Retrofit is sometimes done wing by wing with students occupying remaining wings to allow continued operation of the school. The final retrofit design requires trained contractors/masons to implement.

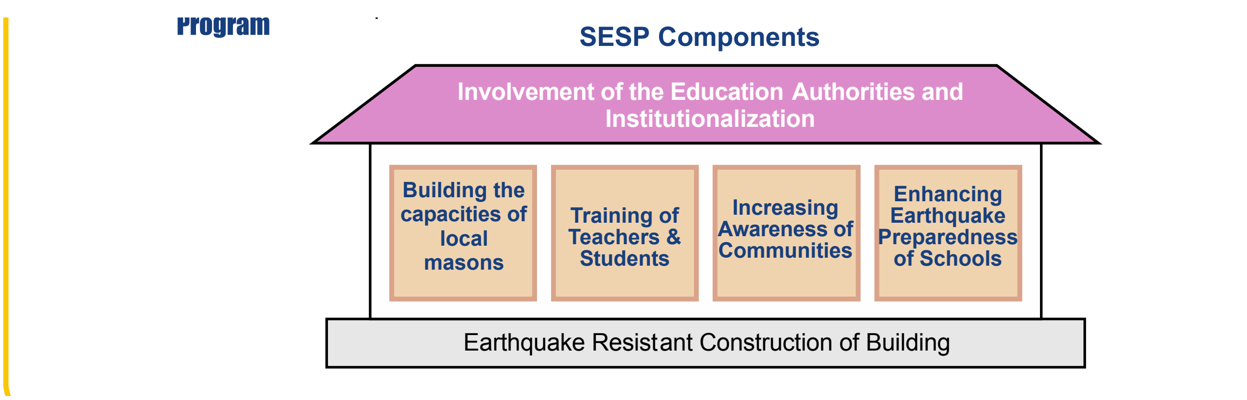


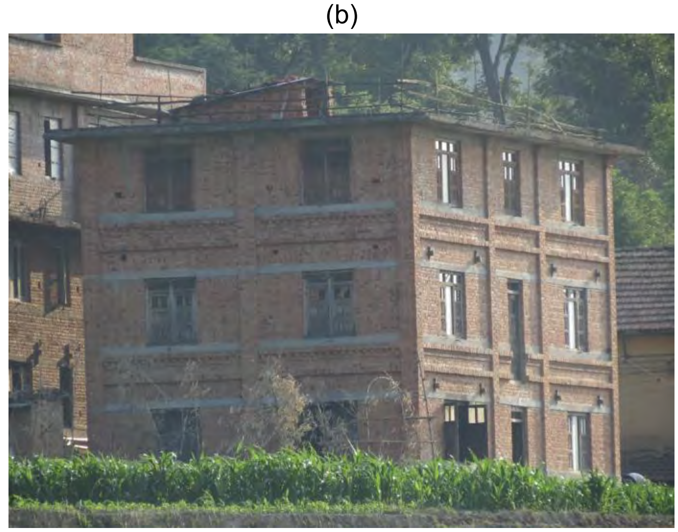
Figure 6-13. Components of the NSET School Earthquake Safety Program (source: NSET, 2014).

The EERI reconnaissance team visited retrofitted schools in the village of Nandikeshwor, Bhaktapur and in Sankhu, Kathmandu. Nandikeshwor is a community with a large number of masons. It was selected as part of the pilot program, and masons were trained in seismic retrofitting techniques. Figure 6-14a shows the original URM brick bearing wall school, which was strengthened in 2000. It was the first school retrofitted in Nepal. Reinforced concrete bands were placed on the walls, and improvements were made in the diaphragms and diaphragm-to-wall ties. It had minimal damage in the earthquake and was green-tagged following the Department of Education's postearthquake safety evaluation. When a new school was needed for a growing population in the village, though masonry construction was used, reinforced lintel bands and corner ties features were employed, based on what the masons had learned, The new school is shown in Figure 6-14b. It is next to the original retrofitted school, and it also had minimal damage in the earthquake. The head mason for both schools is shown in Figure 6-14c. He used his training and experience with improved seismic safety features in the construction of his own home, shown in Figure 6-14d. The mason now states that he incorporates these seismic features as often as possible in his construction practice, thus spreading the impact of school program throughout the community.

(a)

(b)

(c)



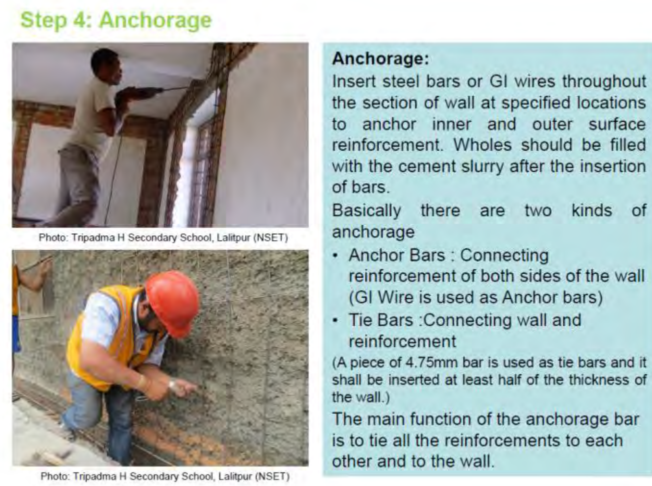
(d)

Figure 6-14. Success of NSET SESP in Nandikeshwor with retrofitted school buildings showing no damage (photos: Hemant Kaushik, unless noted otherwise): (a) First school retrofit in Nepal, (b) Adjacent new school built with improved earthquake resistance, (c) Head mason for each building (photo: Bret Lizundia), and (d) Mason's home built with improved earthquake resistance.

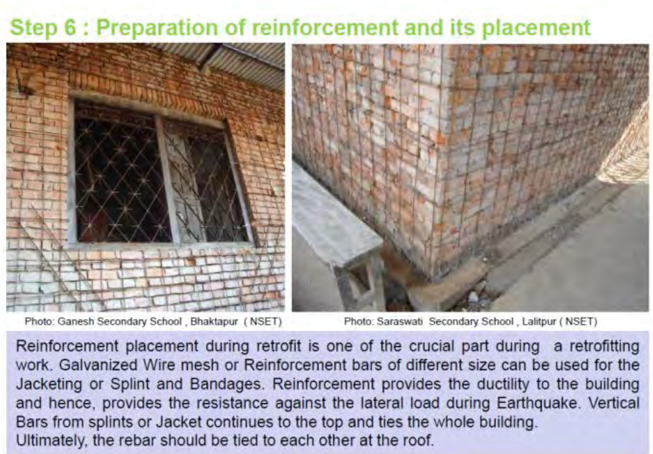
A step by step guide for seismic retrofitting of URM bearing wall buildings was developed as part of SESP, entitled *Quick Reference Guide for Seismic Retrofitting (General Guidelines for the Retrofit of Masonry Buildings)* (Guragain and Acharya, 2013). It covers in-plane and out-of-plane wall enhancement, diaphragm improvements, and diaphragm-to-wall improvements for URM bearing wall buildings. Figure 6-15 shows some excerpts from the guide. In Figure 6-15c, reinforcing for a continuous overlay is shown. Figure 6-15d shows horizontal and vertical bands. The latter approach is more common. Information on diaphragm and diaphragm-to-wall ties is more limited. In some buildings, mud and wood floors were replaced with cast-in-place concrete floors doweled into walls. Typically, roofs and roof-to-wall ties were not installed, and the retrofit relies on a horizontal band at the top of the wall like a bond beam and the vertical bands cantilevering up from the floor.

Figure 6-16a shows a schematic example of the horizontal and vertical bands that were used. Figure 6-16b shows a retrofitted school in Sankhu, with the banding revealed on the inside face in a classroom shown in Figure 6-16c, and the lack of significant changes at the roof level in Figure 6-16d.

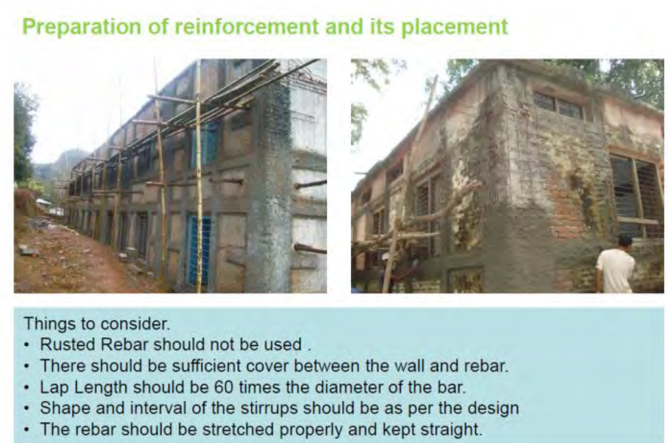
(a)



(b)

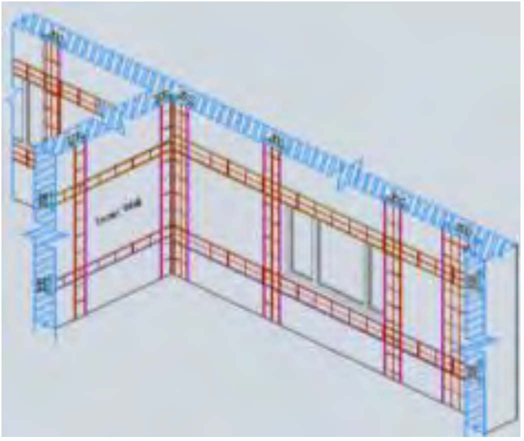


(c)



(d)

Figure 6-15. Selected excerpts from Guragain and Acharya (2013) showing some of the steps in adding cementitious overlays to masonry walls (a) removal of plaster and outer portion of mortar in joints, (b) drilling anchors through the wall to connect the overlays on each side of masonry wall, (c) reinforcing being placed before the overlay, and (d) placement of the overlay.



(a)

(b)

(c)

(d)

Figure 6-16. (a) Typical reinforcing for horizontal bands at lintels and vertical bands at jambs and corners (source: Shreshta, et al. (2012), (b) retrofitted school in Sankhu, Kathmandu (photo: Hemant Kaushik), (c) interior view of finished bands in classroom of retrofitted school in Sankhu (photo: Bret Lizundia), and (d) view of roof over strengthened walls in school in Sankhu (photo: Bret Lizundia).

A survey conducted by NSET following the Gorkha Earthquake has shown that almost all retrofitted school buildings, whether in areas of low or high ground motions, performed very well during the shaking (NSET, 2015).

Table 6-1 provides a comparison of postearthquake evaluation results for buildings in the Kathmandu Valley evaluated by the Department of Education (DOE). It shows dramatically better results for retrofitted buildings than for unretrofitted buildings. For URM brick bearing wall buildings, 70% of the unretrofitted buildings were red-tagged, but only 1.5% of the retrofitted buildings were red-tagged. For RC infill frame buildings, 90% of the unretrofitted schools were red-tagged, and none of the retrofitted schools were red tagged. DOE did not use the yellow RESTRICTED USE tag.

Table 6-1. Kathmandu Valley Rapid Evaluation Data (source: unpublished data, Department of Education, 2015)

Kathmandu Valley Rapid Evaluation Data Provided by DOE					
Building Type	Retrofit Status	Red	Green	Total	Red/ Total (%)
URM Brick	Unretrofit	317	136	453	70
	Retrofit	1	67	68	1.5
RC Frame	Unretrofit	204	49	253	90
	Retrofit	0	18	18	0

Out of 160 retrofitted school buildings in Kathmandu Valley, 125 suffered no damage, and 35 suffered minor cracks during the earthquake. A total of 84 school buildings in the NSET retrofitting program still had their retrofits under construction or in the planning or design stages at the time of the earthquake. Since the retrofits were not complete in these cases, the buildings faced various levels of damage and NSET had the retrofit designs for these buildings re-evaluated based on the actual performance during the earthquake and the current level of building damage. Out of 84 unfinished cases, the designs for 40 buildings were found to be sufficient and can proceed, 29 buildings need further improvement in their retrofit design, and 15 buildings require demolition because the level of damage that occurred makes retrofit impractical (NSET, 2015).

Performance of retrofitted buildings in rural areas was more varied. Paci-Green, Pandey, and Friedman (2015) evaluated a selected set of school case study buildings in different communities, including some that had been retrofit, and conducted detailed interviews with school staff, masons, and community members. They found that retrofitting helped improve performance, but success was dependent on many issues. In one case, a rural retrofitted stone and mud mortar building collapsed. There had been little training of the masons, no engineering oversight during construction, and masons struggled to adapt techniques developed for brick masonry to the stone masonry building. The following summarizes key findings:

- Training of masons and engineering oversight are important;
- Community engagement is essential for success;
- Community needs to understand the rationale and benefit of retrofit;
- Ethnic differences between staff and community can be an issue;
- Signage and displays of mitigation measures are recommended;
- Provide funding transparency;
- Minimize technical design compromises by community;
- Project management is difficult for community;
- Infill masonry walls performed poorly and wall collapse endangered students, even if the structure remained standing; and
- Techniques for stone and mud mortar buildings are needed as typical techniques were developed for the more robust brick buildings.

Examples of good performance are found in Figures 6-17, 6-18, and 6-19. In several locations, the retrofitted school buildings were used as emergency shelters by the people and also as emergency response coordination centers by response organizations (Figure 6-20).

Figure 6-17. Examples of retrofitted school buildings with no damage or very minor damage: (a) Adarsha Ajad School in Bhaktapur without visible damage or cracking, (b) undamaged school in Chhampi, Lalitpur, (c) Gram Sewa School in Dharmasthali, Kathmandu with only minor damage, and (d) children occupying retrofitted school after earthquake (photos: NSET, 2015).

Figure 6-18. *Two adjacent school buildings in Sankhu, Kathmandu. The unreinforced masonry building retrofitted with reinforced concrete jacketing (shown on the left) performed well with limited damage, while the reinforced concrete frame building with masonry infill wall (shown on the right) suffered damage to many columns and cracking in the infill walls (photo: NSET, 2015).*

Figure 6-19. *Partially collapsed non-retrofitted school building assessed as Damage Grade 4 (left) adjacent to an undamaged retrofitted school building (right) in Magargaun, Lalitpur (photo: NSET, 2015).*

Figure 6-20. Examples of school buildings used as shelters: (a) Kanya Mandir School in Kathmandu that was retrofitted in 2014, (b) Baishnavi School in Kathmandu, (c) Bidhyodaya School in Kathmandu that was built with earthquake resistant techniques, and (d) Adarsha Ajad Higher Secondary School in Bhaktpur (photos: NSET, 2015).

6.2.3 Conclusions and Recommendations

Based on field visits and review of available reports by others, preliminary conclusions and recommendations regarding school retrofitting include the following.

- The school retrofitting program should grow. While retrofitting approximately 300 schools to date is an impressive accomplishment, it is a very small fraction of the total number of schools in the country.
- EERI would like more information to understand technical basis of approach and experimental research that was done.
- It would be useful to compare the differences between bands and full overlays, and to study the effectiveness of different diaphragm and diaphragm-to-wall ties.
- Design guidelines have been developed, but they should be published and made more widely available for review.
- Techniques for stone masonry buildings are needed.
- Community engagement and training of masons and engineers are important.
- Increase financial transparency and oversight.
- Falling hazards from infill masonry need to be addressed.
- Additional statistical information and comparisons would be beneficial, particularly outside of the Kathmandu Valley in areas of heavy shaking.

6.3 NONSTRUCTURAL HAZARD MITIGATION EFFORT

Nonstructural elements are those building components and contents that are not part of the structural system of a building, such as windows, partition walls, lighting, equipment, and furniture. In this section, the observed earthquake effects on nonstructural elements, unreinforced masonry partition walls, architectural elements, mechanical and electrical equipment, and other building contents are summarized along with applicable provisions in the Nepal Building Code (Government of Nepal, 1994a) for providing earthquake resistance to these elements. Despite their nonstructural characteristics, damage and collapse of heavy elements (like partition walls) can result in human losses, even when building structural systems are undamaged.

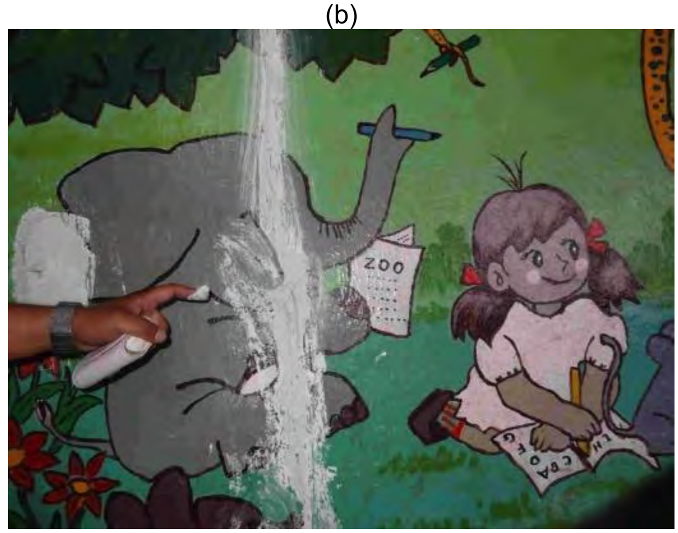
6.3.1 Partition Walls

In many buildings which did not suffer total collapse, nonstructural walls were heavily damaged. In most of these cases, infill walls had no bonding with the RC frame and, as a result, separated from the frame during the earthquake. Unreinforced infill walls developed in-plane shear cracks (Figure 6-21) or, in many cases, collapsed completely along with unreinforced building parapets.

(a)

(b)

(c)



(d)

Figure 6-21. Examples of infill wall damage (a) in a hotel building near Gorkha (photo: Hari Kumar), (b & c) Paropakar Maternity and Women's Hospital in Kathmandu (photos: Hari Kumar), and (d) in Kanti Children's Hospital covered with wall putty. (photo: Judith Mitrani-Reiser).

The Nepal Building Code Sections NBC 105:1994 (Government of Nepal, 1994b) and NBC 205:1994 (Government of Nepal, 1994c) provide requirements for addressing nonstructural hazards. In NBC 105: 1994, these are referred to as secondary hazards in Chapter 12 of the standard titled "Seismic Design Requirements for Secondary Structural Elements, Architectural Finishes and Mechanical and Electrical Equipment." In the NBC 205:1994, Chapter 8 requires band reinforcement details of non-load-bearing walls and partition walls. Clause 8.1.1 indicates that:

- To prevent walls from falling out, [non-load-bearing walls] shall be provided with horizontal reinforced concrete (RC) bands through the wall at about one-third and two-thirds of their height above the floor in each storey. The width of the band should be equal to the wall thickness and its thickness equal to that of the masonry unit, or 75 mm, whichever is larger.
- Reinforcement: (a) Longitudinal - two bars 8 mm in diameter (Fe415) anchored fully in the RC column abutting the wall. (b) Transverse - links 6 mm in diameter (Fe250) stirrups at every 150mm.

However, the Gorkha Earthquake has reiterated the need for updating the nonstructural provisions of the codes to better align with other international standards that require improved connections between structural and nonstructural elements, such as the International Building Code, the New Zealand Standard for Earthquake Actions (NZS 1170.5), and the Eurocode 8.

The current code provisions for nonstructural elements are largely ignored even in the construction of Government buildings such as the hospitals. Similar disregard for nonstructual provisions related to partition walls was observed in several large scale construction projects that suffered damage including schools and privately owned commerical buildings (see Chapter 5, Sections 5.2 and 5.3 for more information about building codes and performance of reinforced concrete frame buildings with infill walls).

6.3.2 Architectural Finishes

The EERI reconnaissance team observed damage to architectural finishes including external and internal cladding tiles and other adhered finishes, glazing, and suspended ceilings. Damage to glazing and interior building finishes posed a risk to the public as dislodged pieces fell on to the building periphery and also made several exits unusable (Figures 6-22 and 6-23). Damage to both plaster and tiled suspended ceilings disrupted functionality, especially in health facilities, department stores, and other similar large scale buildings (Figure 6-24). The NBC does not refer to plaster ceilings at all; however, Table 12.1 in the NBC 105:1994 sets provisions for suspended ceilings, although only for tiles weighing more than 2 kg each (Government of Nepal, 1994b).

(a) (b)

Figure 6-22. Glazing damage in Paropakar Maternity and Women's Hospital, Kathmandu (a) in nurses station and (b) in VIP block (photos: Hari Kumar).

(a)

(b)

Figure 6-23. Spalling off of adhered tile finishes in two buildings in Kathmandu, both preventing easy egress from the buildings (photo a: Hari Kumar, and photo b: Judith Mitrani-Reiser).

(a)

(b)

Figure 6-24. (a) Damage to plaster ceiling close to the walls in Grande Hospital, Kathmandu and (b) damage to acoustic ceiling tiles; however, photo b also shows good performance of flexible connections between the water branch line to the sprinkler heads (photos: Hari Kumar).

6.3.3 Contents

Building contents including cupboards, computers, and most furniture were dislodged and damaged in several locations visited by the EERI team (Figure 6-25); however, most undamaged displaced content had been restored at the time of the team's visit. Several hospitals reported loss of equipment in cases where this equipment had not been seismically anchored. Some schools reported loss of computers and science lab supplies, in cases where nonstructural mitigation measures had not been carried out prior to the earthquake.

(a) (b) (c)

Figure 6-25. Damage to storage cabinets and other furniture at various hospitals (photos: Hari Kumar).

6.3.4 Rooftop Elements

Several rooftop elements such as unanchored solar panels and plastic water tanks were dislodged. There are no provisions in the Nepal Building codes for anchoring of roof top elements.

Figure 6-26 contrasts two sets of roof top solar panels. One unachored panel array suffered damage and was not functional, while the other anchored array remained fully functional.

Plastic water tanks on rooftops were often observed to be unanchored and placed on minimal 'supports' without restraints or flexible connections as shown in Figure 6-27. While many of these support structures and tanks were found unaffected by the earthquake shaking, this may not be the case in future earthquakes. The Nepal Building Code should introduce guidance on provisions for anchoring of rooftop elements for earthquake safety.

(a) (b)

Figure 6-26. (a) Damaged and dysfunctional array of solar panels atop a building in Aanbu Khaireni, Tanahun District because the panel on the left had not been anchored (photo: Hari Kumar) and (b) well anchored array of solar panels at the Bir Hospital Kathmandu that remained functional (photo: Judith Mitrani-Reiser).

(a)

(b)

Figure 6-27. Examples of plastic rooftop water tanks that are unanchored and placed on minimal 'supports' without restraints or flexible connections (photo a: Judith Mitrani-Reiser and photo b: Hari Kumar).

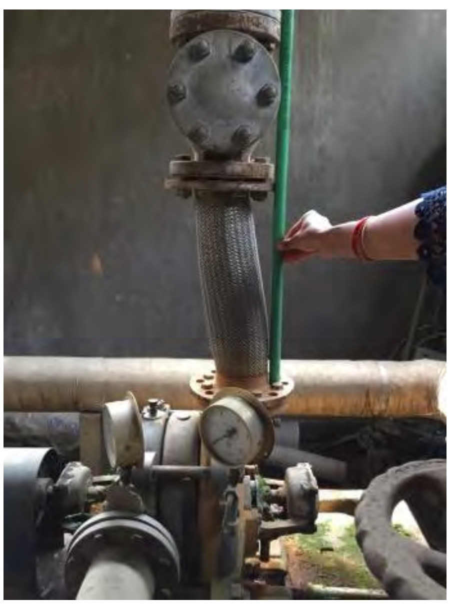
6.3.5 Good Practices

The dangers posed by nonstructural hazards have been understood in Nepal for over a decade, and several projects have addressed the issue in the recent years (NSET, 2012, GHI, 2013). The team observed the nonstructural mitigation and preparedness efforts at the Tribhuvan University Teaching Hospital which helped the hospital continue functioning better than most other hospitals in Kathmandu. Several other examples of good performance were observed at the Kanti Children's Hospital that was built with technical support from the Government of Japan. Figure 6-28a shows tall water tanks with superior anchorage detailing; however, this practice does not seem to have been replicated in tanks commissioned on the hospital premises since its initial construction. Figure 6-28b shows an example of a raised water tank support structure, similar to what is commonly seen across Nepal. In the case shown, the legs are poorly anchored with blocks of plain cement concrete and the side restraints may not be strong enough to keep full tanks from sliding off or tipping over. Even these limited mitigation measures, however, are an improvement over the previous practice of no anchorage at all. Figure 6-29 shows examples of flexible connections at both hospitals that also helped to prevent damage and leaks of water and fuel.

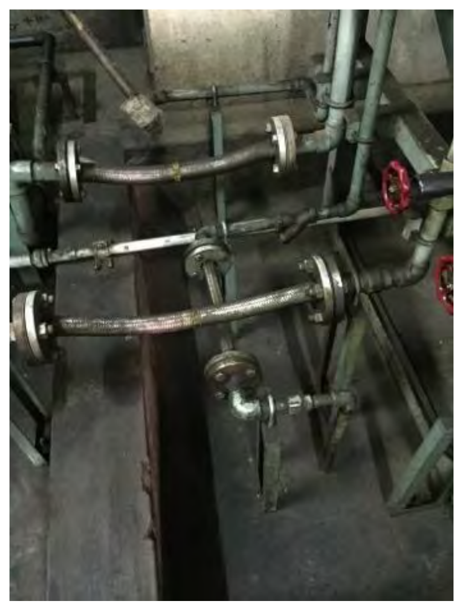
(a)

(b)

Figure 6-28. (a) Anchored tall water tanks provided at the Kanti Children's Hospital built with technical support from the Government of Japan performed well (photo: Judy Mitrani-Reiser) and (b) a raised water tank support structure with minimal anchorage details including plain cement concrete at base supports and side restraints that may not be strong enough to keep full tanks from sliding off (photo: Hari Kumar).



(a)



(b)

Figure 6-29. Flexible connectors seemed to have prevented the connections from breakage during the earthquake (a) in the water supply system at the Tribhuvan University Teaching Hospital (photo: Hari Kumar) and (b) in the generator fuel supply line at the Kanti Children's Hospital (photo: Judith Mitrani-Reiser).

Several schools completed retrofitting projects prior to the earthquake to anchor contents such as cupboards in libraries and science labs (Paci-Green, et al., 2015). Figure 6-30 shows an example of the retrofitting techniques used in retrofit programs supported by NSET (2016).

(a)

(b)

Figure 6-30. Examples of anchorage details used for cupboards and bookshelves in schools retrofitted by NSET prior to the earthquake (photos: Surya Acharya).

Despite the positive performance shown in the previous examples, these efforts have been limited to a small number of schools and hospitals and have not spread to the community at large. Even in the health and education sectors, these have been limited to efforts by agencies such as NSET and the Ministry of Education. Earthquake design of nonstructural elements is crucial, especially for lifeline structures that have to remain functional following an earthquake.

In order to ensure that non-structural mitigation designs and practices are widely adapted, the Nepal National Building code needs to make necessary changes and add guidance and regulations for the safety of non-structural components such as architectural finishes, infill walls, suspended ceilings, veneer, other adhered wall tiles, parapets, water tanks, other rooftop elements, etc. Building codes across the world have been incorporating provisions on non-structural elements for almost a century (FEMA, 2015). Taking lessons from the 1906 San Francisco earthquake and the 1925 Santa Barbara earthquake, the Uniform Building Code (ICBO, 1928) used in California was updated to include provisions for nonstructural elements as early as 1927. Lessons from several earthquakes since then have shaped the latest versions of international codes such as the International Building Code (ICC, 2014) and the NEHRP Recommended Seismic Provisions for New Buildings and Other Structures (BSSC, 2009). Using these versions as reference points, as well as the experience from the recent earthquakes, specific implementable provisions for nonstructural elements should be incorporated into the Nepal Building Codes before the window of opportunity provided by the 2015 Gorkha Earthquake closes.

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CHAPTER 7

CULTURAL HERITAGE SITES

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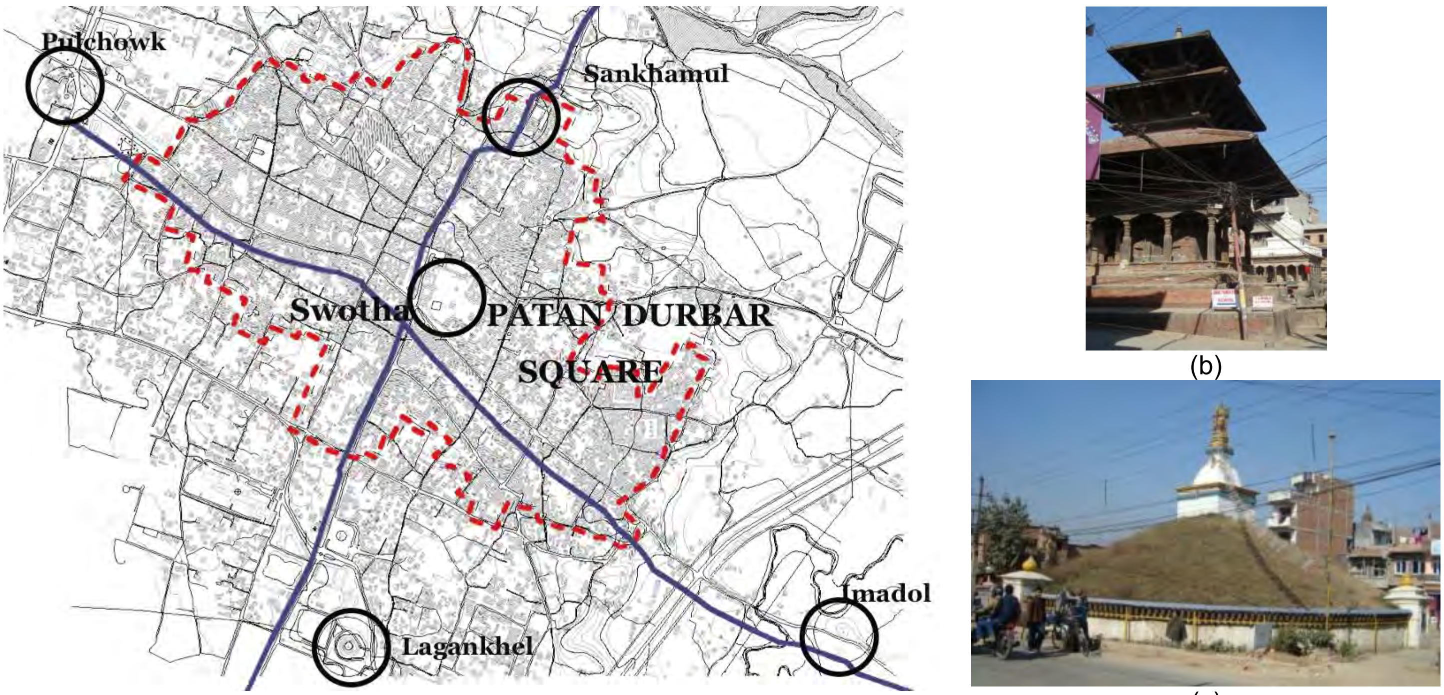
Acknowledgements:

My special thanks go to Professor Dr. S.R. Tiwari and Professor P.N. Maskey for sharing their views, and to Ram Gopal Shrestha from Bhaktapur Municipality, Rohit Ranjitkar from Kathmandu Valley Preservation Trust, Sampat Ghimire and Devendra Bhattarai from the Department of Architecture, and Amrit Man Buddhacharya from the Swayambhu Management and Conservation Committee for providing tours of damaged sites.

7.1 INTRODUCTION

Kathmandu Valley has three primary historic towns: Kathmandu, Patan, and Bhaktapur. These towns were planned with orientation to the laws of the gods and the cosmos. The borders of the towns were designed and built to match an image of cosmos. Patan was planned with a layout corresponding to the Dharma Chakra (Buddhist Wheel of Righteous) with its main streets running in two cardinal directions bounded by four thurs (mounds) at Lagankhel, Imadol, Sankhamul and Pulchowk (Figure 7-1). These main streets meet near Swotha. The central part of Patan is the Durbar Square (the Royal Palace). There are hierarchies of streets with main streets, secondary streets, and funerary roads. Districts are formed around neighborhood squares. Nodes, districts, and edges are delineated by temples and stupas. In the Kathmandu Valley, temples are central to community life because they provide the focal point and organization of each neighborhood. Outside Kathmandu Valley, every village has its own shrine and various temples as well. As stated by Professor Madhav Gautam from Tribhuvan University (Shrestha, 2015b), “Kathmandu is a city for which the cultural sites are part of its skeleton. If you take them away, the city collapses.”



(a) (b) (c)

Figure 7-1. (a) Map annotating layout of Patan in Kathmandu Valley, (b) Swotha Narayan Temple at Swotha Node, and (c) Imadol Thurs (photos and map annotations: Suraj Shrestha).

Nepal has both cultural and natural sites included in the list of UNESCO World Heritage sites. UNESCO Natural Heritage Sites include Chitwan National Park and Sagarmatha National Park. UNESCO Cultural Heritage Sites include seven monumental zones of Kathmandu Valley plus Lumbini, the birthplace of Buddha, which lies in the southern belt of the country. Of the Kathmandu Valley Heritage Sites, three are the Durbar Squares of Kathmandu, Patan, and Bhaktapur; two are the Hindu temples of Pashupatinath and Changunarayan; and two are the Buddhist stupas of Swayambhu and Boudhanath (UNESCO, 2016).

7.2 TYPOLOGIES OF HERITAGE STRUCTURES

In terms of architectural pattern, Nepalese temples can be broadly classified into three groups (Korn, 1989), as shown in Figure 7-2. The first group is a tiered temple having roofs with diminishing dimensions as the temple rises, similar to a pagoda style. The roofing system of the tiered temples can be distinguished as one-roof, two-roof, three-roof, or five-roof temples. There are no four-roof temples. These temples have wide eaves supported by carved wooden struts. The second group is the Stupa, which is purely Buddhist in concept and execution. The outstanding feature of stupas is a hemispherical mound topped by a square base supporting a series of 13 circular rings. Narrowing towards the top, these rings are crowned by parasol. The top portion rests on a central wooden post. The third group is the shikhara style which has a superstructure composed of a tall curvilinear or pyramidal tower. The tower surface is broken up vertically into five or nine sections (Jaishi, 2003).

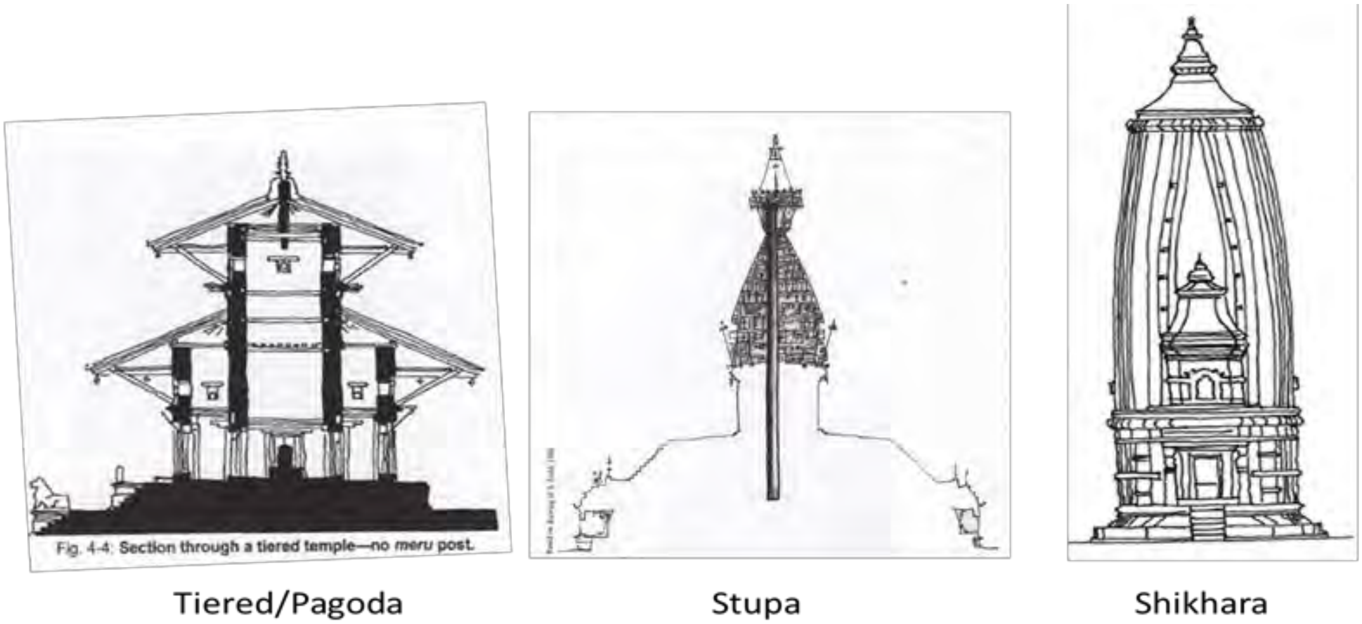


Figure 7-2. Three different architectural styles of Nepalese heritage structures (source: Tiwari, 1989).

Based on construction characteristics, there are three basic typologies of cultural heritage structures in Nepal, as shown in Figure 7-3: brick masonry with timber, brick masonry without timber, and stone.

The first typology consists of temples with one to five diminishing tier symmetric structures made from brick masonry and timber structural elements (Figure 7-3a). The ground floor consists of a Sal wood (Shorea Robusta) timber framing system, which supports the wall above it (Figure 7-4). The timber columns on the base level stand on the base stone with a small pin inserted on the stone base. The top of the timber columns has a pin that extends into the beam above. The beam has a bracket, and it supports battens or joists upon which planks are laid. These in turn support the final floor finish. Additional lateral bracing is provided by linking the vertical and horizontal structural components to prevent relative sliding of the floor structure on the walls, thus creating a box behavior response. This connection is made using wedges or timber pegs that fix the wall plate along the perimeter through the joists that run both inside and outside the building.

(a) (b) (c)

Figure 7-3. Three typologies of heritage structures per construction material, (a) PashupatiNath Temple – brick masonry with timber structure (photo: Suraj Shrestha), (b) Bhimsen Tower – brick masonry (source: Kelly, 2015), and (c) Krishna Temple – stone (photo: Suraj Shrestha).

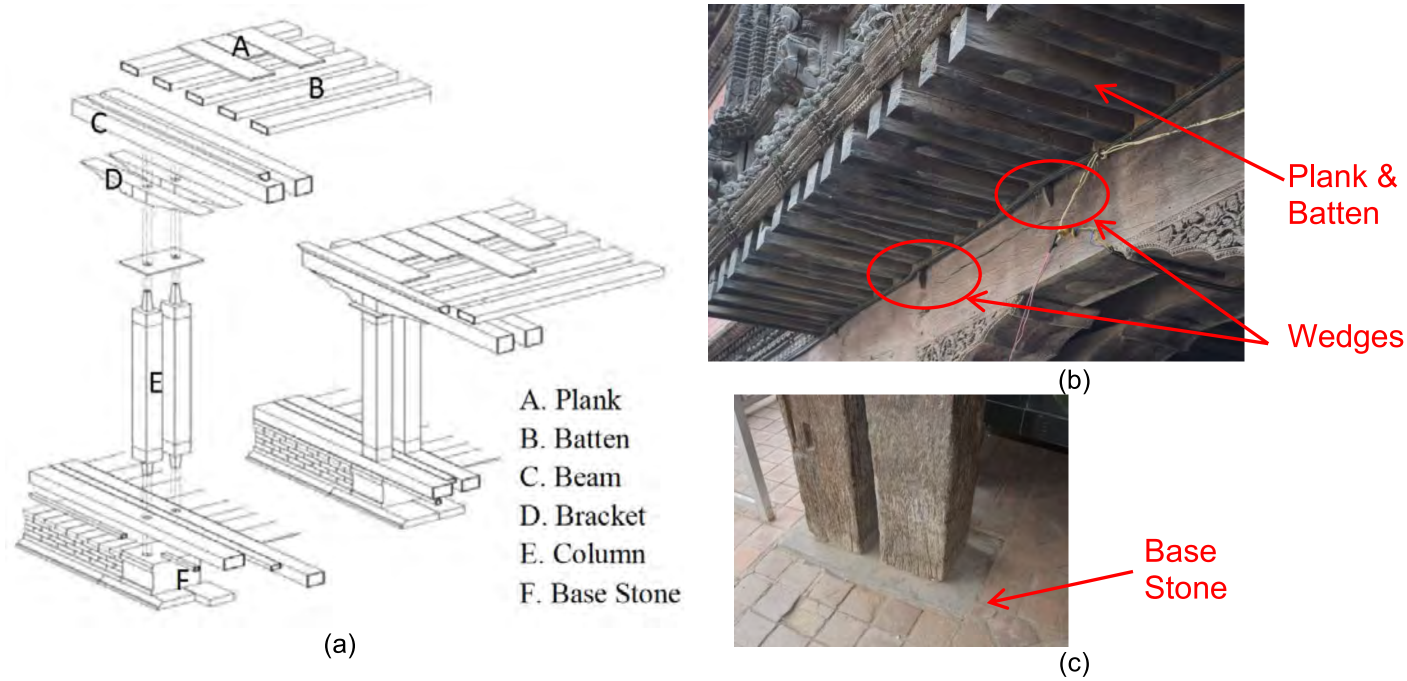


Figure 7-4. Typical framing and construction details for a wood-framed temple: (a) primary framing components (sources: Shakya, 2012, Bonapace et al., 2013), (b) examples of planks, battens, and wedges, and (c) connection of wood column on base stone (photos and annotations: Suraj Shrestha).

The second typology consists of brick masonry structures in lime or mud mortar. These are typical load bearing masonry structures with no timber frames that contain only nonstructural timbers, if any. Bhimsen Tower (also called as Dharahara) is a typical example of this type. It was a nine-story unreinforced brick masonry tower built in 1825 with a height of 203 feet. The main material used in the building construction is *Vajra*, which is a typical Nepali material made from “Surkhi” or brick dust, “Chuna” or lime, “Mas ko Dal” or black lentils, and “Chaku” or caramel. There is typically no iron reinforcement in this Vajra material, as was the case for the Bhimsen Tower. This tower was completely destroyed by April 25 main shock as shown in Figure 7-3b.

Typical load bearing masonry structures for temples and palaces have walls that consist of three layers (Figure 7-5). The outer face of wall is made of fired clay brick with smooth finishing called as “dachiapa,” and the inner face is made of sundried bricks called as “kachiapa.” Outer and inner face layers are not well connected, with the middle core wall not connected to the outer faces. Normally, the middle core is filled with rubble stone, brick bats, and mud. The bonding mortar inside the massive walls is not visible from the outside but has a very large influence on the structural strength and resistance of the temple. In many temples, yellow colored clay mortar, mud mortar, and more rarely lime-surkhi mortar are used. Though the thickness of the walls ranges from 50 cm to 75 cm, poor bonds between the outer and inner face layers often results in typical failures like delamination and bulging of the stiffer face brick shell.

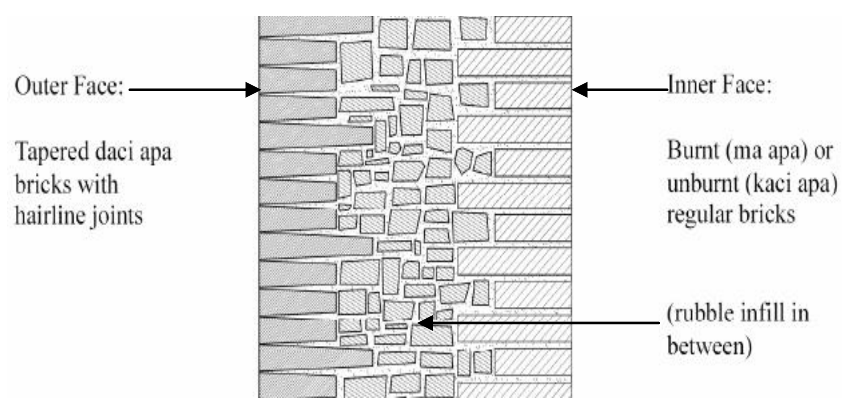


Figure 7-5. Three layers in a typical brick masonry wall in Nepal (source: Beckh, 2006).

The third typology consists of temples made from stone. Krishna Temple of Patan Durbar Square is the famous stone temple of this type, which was built in 1723 (Figure 7-3c). It did not suffer any damage from the Gorkha Earthquake or aftershocks; however, another stone temple called Vatsala Devi Temple of Bhaktapur Durbar square built in 1672 was completely destroyed by this earthquake.

7.3 EXTENT OF IMPACT

Many cultural heritage structures in Nepal, primarily in the Kathmandu Valley, suffered extensive damage as shown in Figure 7-6. Nearly 750 monuments from all over the country were damaged with approximately half suffering collapse. Though the scale is huge, damage is less than some media reports have implied. Out of the seven UNESCO World Heritage monument zones in Kathmandu Valley, five suffered varying levels of damage. Among them, Kathmandu Durbar Square suffered greatly with nine temples that completely collapsed and another 20 monuments that were partially damaged. Three temples in Bhaktapur Durbar Square collapsed, and two temples in Patan Durbar Square collapsed. Swayambhu monument zone also suffered heavy damage though the main shrine was not damaged. Changu Narayan temple was also partially damaged. Nonetheless, there are several iconic temples and monuments that survived in all the World Heritage sites.

(a) (b)

Figure 7-6. Examples of damage to cultural heritage sites: (a) Kathmandu Durbar Square, and (b) Bhaktapur Durbar Square (photos: Suraj Shrestha).

In the Government of Nepal's Post Disaster Needs Assessment (NPC, 2015), it is estimated that the total value of disaster effects caused by the earthquakes is 706 billion Nepalese Rupees (NPR), or approximately 7 billion U.S. Dollars. Of that amount, only 19 billion NPR (about 2.75% of the total effects) accounts for the effect to cultural heritage sites. While in percentage the impact is relatively small, the indirect effect of this damage is much larger because it has resulted in a reduction in tourism, which has large impacts on the Nepalese economy. Similarly, the total needs for reconstruction required for cultural heritage sites amounts to 21 billion NPR, which is about 3.1% of the 669 billion NPR total reconstruction costs for all sectors. Nepal will require substantial external assistance to meet the rehabilitation and reconstruction costs for these heritage structures (NPC, 2015).

7.4 DAMAGE PATTERN

Damage to heritage structures was influenced by many factors including location and topography, maintenance level, age, structural type, material quality, and configuration. Many of these factors are described with representative examples below.

7.4.1 Damage Variation due to Location and Topography

The performance of monuments in the earthquake varies greatly from monument to monument and from place to place. Despite similar construction materials and architectural features, some monuments collapsed at one location while others at a different location survived. In some other cases, nearly identical monuments on the same site suffered vastly different levels of damage (Figure 7-7). For example, in Patan Durbar Square, many temples remained standing, but a few temples like Char Narayan and Sankhar Narayan completely collapsed. In Kathmandu Durbar Square, the Kasthamandap, Maju Dega, Narayan Vishnu, Trailokya Mohan, and Chasin Dega Temples were heavily damaged.

(a)

(b)

Figure 7-7. Examples of varying degrees of damage to similarly constructed temples at Swayambhu: (a) Anantapur Temple with a collapsed superstructure, and (b) Pratappur Temple with an undamaged superstructure and some limited plinth damage (photos and annotations: Suraj Shrestha).

Topographic effects that weaken or amplify the earthquake shaking at certain sites may also be a reason why some structures fell and some survived. The effects of hilltop amplification were seen clearly in Swayambhu which lies atop the crest of a hill (Figure 7-8a).

The underlying geological conditions below temples—including the depth of the water table, thickness and type of sediments, and proximity of bedrock to the surface—may also be major contributing factors; however, limited studies have been conducted on geological conditions for most temples. Most of the temples of Taumadhi Square in Bhaktapur including Nyatapola suffered much less damage not only in this earthquake (Figure 7-8b) but in previous earthquakes as well, which may be due to the nature of the soil. Detailed study is needed to verify this possible conclusion.

(a)

(b)

Figure 7-8. (a) Hilltop amplification may have exacerbated damage in Swayambhu (source: Albinger, 2015), and (b) Taumadhi Square of Bhaktapur suffered less damage in many historic earthquakes, which may be due to its underlying soil characteristics (source: Rauniar, 2015).

7.4.2 Maintenance, Restoration, and Retrofit

In some cases, retrofit or other maintenance improved monument performance. Chyasilin Mandap in Bhaktapur Durbar Square was seismically strengthened and was undamaged.

Pratappur Temple of Swayambhu suffered minor damage to its plinth. Maintenance of the superstructure of this temple was done after being damaged partly by fire in 2003 and by lightning in 2011. However, the similar, adjacent temple Anantapur had not received any recent maintenance and experienced superstructure collapse (Figures 7-7 and 7-8a).

Restored monuments also performed well (Figure 7-9). The 55 Window Palace in Bhaktapur Durbar Square had been restored and only showed evidence of minor damage. Similarly, the timbers of Bhimsen Temple in Patan Durbar Square had also been repaired, and the temple performed well in this earthquake.

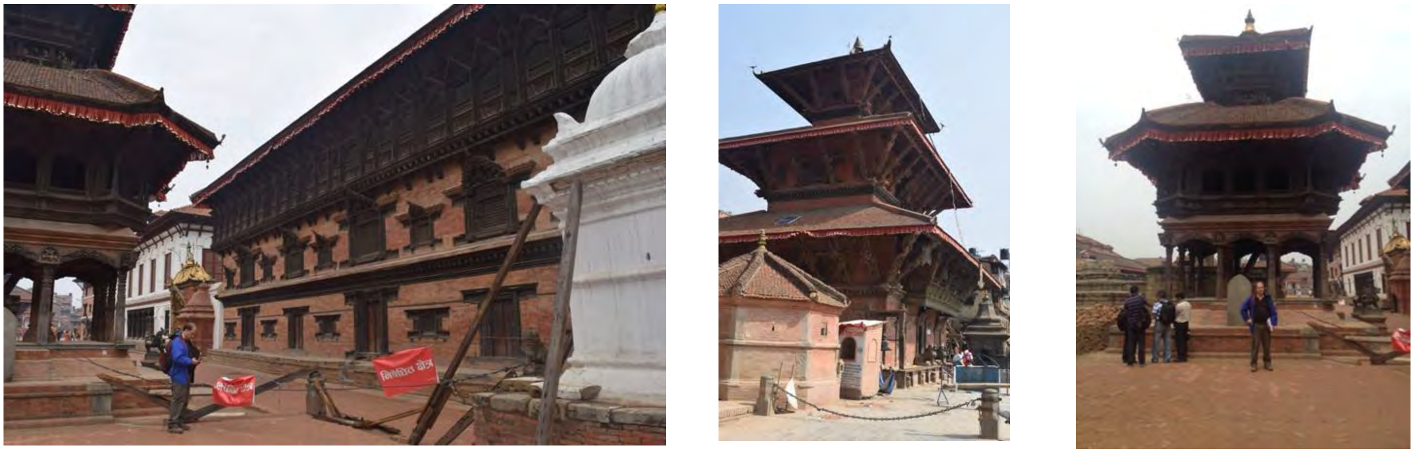


Figure 7-9. Restored monuments performed well: (a) 55 Window Palace of Bhaktapur Durbar Square, and (b) Bhimsen Temple of Patan Durbar Square, and (c) Chyasilin Mandap of Bhaktapur Durbar Square (photos: Suraj Shrestha).

7.4.3 Structural Type

One clear conclusion that can be drawn from the damaged heritage sites and monuments is that brick masonry combined with timber frame structures typically performed better than massive unreinforced brick masonry structures in lime or mud mortar. For example, the main structure of Changu Narayan Temple, which relies on a timber frame structure, did not collapse even though some the brick masonry walls suffered out-of-plane collapse (Figure 7-10a).

(a) (b)

Figure 7-10. Temples supported by timber structures with brick masonry infill performed better than pure masonry structures: (a) Changu Narayan Temple, and (b) a temple in Kathmandu Durbar Square (photos and annotations: Suraj Shrestha).

The most commonly observed damage to these multi-tiered wood frame temples was collapse of their top stories even though the lower portions remained intact, as shown in Figure 7-11. The top tier of Patan’s Taleju Temple and Jayabageshwori Temple of Gaushala, Kathmandu collapsed. The nine-story palace or the Basantapur Tower of Kathmandu Durbar Square also lost its top two floors in the earthquake.

(a)

(b)

(c)

(d)

Figure 7-11. Examples of the collapsed upper stories of multi-tiered temples: (a) Taleju Temple in Patan Durbar Square (source: Shrestha, 2015a), (b) Jayabageshwori Temple in Gaushala, Kathmandu, (c) close view of pounding effect between nine-story Basantapur Tower of Kathmandu Durbar Square and Gaddi Baithak, and (d) the nine-story Basantapur Tower of Kathmandu Durbar Square (shown in center) lost two top stories (photos and annotations: Suraj Shrestha).

Another structural type, Buddhist stupas, performed relatively well, perhaps due to their dome shape. In Boudhanath Stupa, there were small cracks in the main dome, and the ninth, tenth, and eleventh steps were displaced slightly (Figure 7-12a). The displacement of the steps was small after the April main shock, but increased after the May aftershock. The main stupa of Swayambhu was not damaged, even though many surrounding monuments of pagoda and shikhara styles were fully collapsed or partially damaged (Figure 7-12b).

(a)

(b)

Figure 7-12. Most Stupas performed well: (a) Boudhanath Stupa (source: Explore Himalaya, 2015, Bodhivastu, 2015), and (b) SwayambhuStupa (source: BBC, 2015).

7.4.4 Configuration

The damage sites investigated by the EERI team showed that tall monuments on narrow bases suffered more damage (and often collapse) when compared to low rise masonry monuments. The high aspect ratio increases overturning demands on the temple base and reduces global stability. Although strong motion recordings of temples are not available and dynamic properties of temples are not well known, it is possible that the taller monuments have longer fundamental periods and are more likely to experience higher levels of spectral acceleration. The Gorkha Earthquake had comparatively high spectral response at longer periods. See Chapter 2 for more details.

The foundations of most temples have rarely been studied in depth because conservation work is usually done from the plinth upwards (Shakya, 2012). Observations of existing temples with a wide plinth base show that the foundations are usually just as wide as the plinth platform and appear to have a masonry mat built directly on the ground level or on a thin brick underlayment level. However, temples with shallow plinths appear to rise from some depth below ground. Whatever may be the foundation, it was observed that most of the tiered temples with wide plinth bases performed well despite some examples of bad performance (Figure 7-13). Nyatapola, the famous five-tiered temple of Taumadhi Square in Bhaktapur was built in 1702 and has been standing intact for 314 years, surviving the great earthquakes of 1833, 1934, and 2015. It has a wide base with five levels (Figure 7-13b). Similarly, Taleju Bhawani temple of Kathmandu Durbar Square built in 1564 survived the earthquake with its wide plinth base (Figure 7-13a). Despite these good examples, there are few other multi-tiered temples like Maju Dega Temple of Kathmandu Durbar Square built in 1690 that had a wide plinth base but still collapsed (Figure 7-13c).

(a) (b) (c)

Figure 7-13. Most of the temples with a wide plinth base performed well though a few collapsed: (a) Taleju Bhawani Temple of Kathmandu Durbar Square (photo: Suraj Shrestha), (b) Nyatapola in Bhaktapur built in 1702 survived Great Earthquakes of 1833, 1934 and 2015 (photos: Suraj Shrestha), and (c) Maju Dega of Kathmandu, a tall multi-tiered temple with a wide base, collapsed (in foreground) while other low rise masonry structures on site performed well as indicated by the circled building in the rear center of the photo (source: Shrestha, 2015c).

7.4.5 Pounding

Though rare, a few examples of pounding effects were also observed between buildings. Figure 7-11c shows the hammering effect between Gaddi Baithak and the neo-classical European style building with the roofs of the nine-story Basantapur Tower in the Nasal Chowk of Kathmandu Durbar Square.

7.4.6 Material Quality and Deterioration

Another main reason for failure of heritage structures is the quality of materials and construction. Some of the brick quality, especially in the neo-classical building of Gaddi Baithak in Kathmandu Durbar Square, was poor compared to other heritage buildings. This resulted in failure to the outer layer of the walls (Figure 7-14a).

Poor maintenance and deterioration was also repeatedly reported as the main cause of failure. This deterioration was often exemplified by rotten wood members (Figure 7-14b). Loose capitals, deterioration of the timber column dowel connecting the column to the stone base, or loose connections between timber columns and beams have also been reported to be the cause of damage in some cases.

(a) (b)

Figure 7-14. (a) Poor quality of bricks in a neoclassical heritage structure in Kathmandu Durbar Square, and (b) rotted timber taken out from a collapsed temple in Kathmandu Durbar Square (photos: Suraj Shrestha).

7.4.7 Age

Building age also appears to be another factor influencing failure. Kathmandu Valley has temple structures from the early 16th century though their history dates back even further. For example, Kasthamandap in Kathmandu Durbar Square from where the name of Kathmandu was derived, was reportedly built in the early 16th century from the wood of a single tree. The earthquake caused severe damage to the temple and its ultimate collapse. Similarly, Char Narayan Temple (also called as Jagannarayan Temple) is perhaps the oldest temple in Patan Durbar Square. Some scholars believe it was built in 1565, while others suggest the early 17th century as a more reasonable date. This temple also completely collapsed.

Pashupatinath Temple was built at the end of 17th century (though its existence dates back to 400 AD), and it is a good example of old temples that survived the earthquake. The two-tiered temple is not very tall, so it may have been less affected by long period ground motion. Another reason for its good performance may be its timber frame structure which may add ductility. Wooden wedges rather than nails were used for all timber connections which added flexibility to the interlocking system. The two-tiered temple has a configuration that makes the top lighter than the heavy bottom. Pashupatinath has been renovated a couple of times in the recent past, which also may have contributed to its good performance. Another possible explanation for reduced damage is the configuration of its roof. The bottom roof is wide enough to cover the base thus preventing rain and sunlight from making direct impact on wooden structures of the temple frame, therefore minimizing the deterioration of the temple over the years. This temple demonstrates how earthquake performance (either good or bad) was influenced by many different factors (Honey Guide, 2015).

7.5 ISSUES IN REBUILDING OF HERITAGE STRUCTURES

Now that Nepal is rebuilding its heritage sites, a key question arises about whether to rebuild with traditional techniques and materials or include some form of enhancement? Professor Tiwari from Tribhuvan University and several other conservationists argue that the earthquake failures are failures of maintenance, not failures of technology or material. Other engineers disagree. But before coming to any conclusion, detailed study and careful analysis of these traditional techniques as compared to the performance in this earthquake need to be undertaken. There is no doubt that usefulness of local technology should not be devalued, but its effectiveness should be verified. These temples do have quite a few features that have potential to reduce the impact of earthquakes like square plan with full symmetry, a triple wall structure such as shown in Figure 7-5, double framing of openings on both sides of the thick wall with cross ties in between, temple core walls, roof tied to walls, diminishing load consecutively in upper floors as their size decreases, ring ties or bands of reinforcement in the wall, use of wedges, struts supporting the large roof overhangs, etc. But there is always room for improvement. These local technologies should be enhanced in the light of advances in engineering. It is possible to include some forms of enhancement that should not be objectionable to conservationists. For example, introducing modern retrofitting techniques to support the structure but hiding the enhancements to the viewers by covering them with local traditional materials could be a compromise between the conservationists and structural engineers.

A positive aspect of the rebuilding process is that there are plenty of available artists and masons who can produce structures with high quality traditional materials and finishes. From the era of the Malla kings, a caste system was used in Nepal to indicate each person's profession. The planning of towns was also done in such a way that people having same profession were kept in a same neighborhood. Even to this day, this tradition remains in the city cores of Kathmandu Valley. For example, Shilpakars is a caste of Newars living in Ikha Lakhu of Patan who still retain their ancestral profession of wood carving. Similarly, there are separate neighborhoods of people working in metals, stones, etc. Since many of these people still continue their ancestral profession, it should be possible to rebuild many heritage structures with the traditional characteristics and styles.

Another positive aspect for rebuilding is the community-based management for the heritage sites. Guthi is a traditional community organization system that still binds Nepalese society. Heritage sites are owned and operated by a community based trust which undertakes activities to preserve their culture and tradition. These intangible assets could be used positively in rebuilding process.

On the contrary, there are other issues in rebuilding which could be improved. First, the Department of Archeology, the sole government agency to look after the archeological sites, has a very small staff size to manage the scale of damage. At the time of the Gorkha Earthquake, per discussions with department staff, the EERI team was told that there was only one architect, 13 civil engineers, and 12 archeologists in the department who are responsible for the entire country.

Second, apart from few exceptions, neither the Department of Archeology nor any other agencies have proper documentation and records of art and artifacts including architectural and structural drawings of monuments. To rebuild with authenticity will be a major challenge.

Third, another challenge will be to reach consensus on plans for rebuilding. Though the Department of Archeology is seeking advice from experts, how to reach consensus is a problem because there are no specific guidelines or standards or repair and rehabilitation of heritage structures in Nepal (except a few work procedures and an integrated management plan).

Fourth, funding can be another issue impacting rebuilding in a country like Nepal. However, apparently foreign donors and agencies pledged more than $3 billion in aid during a Donor Conference held in Kathmandu on June 25, 2015. The Government of Nepal has also given priority for rebuilding in the budget of new fiscal year. Given the scale of the damage and the beauty and cultural significance of the heritage structures, proper management of donor and government funding, and the repair work itself will be both essential and very challenging.

Lastly, technological issues are another challenge in rebuilding of cultural heritage sites, according to Mr. Rohit Ranjitkar, a conservation architect who is country director of the non-profit Kathmandu Valley Preservation Trust (KVPT), and his friend Dilendra Shrestha, a past president of the Patan Tourism Development Organization (Shrestha, 2015b), "Heavy roofs of palaces inside the courtyard of palaces need to be uplifted. The challenge is to remove it, make the repairs and then put it back. A crane can't be brought into the area. So, a helicopter has to be brought to lift it off and then put it back on." These construction challenges are complicated to coordinate and expensive to implement.

7.6 RECOMMENDATIONS

Based on observations during the EERI reconnaissance trip, the author makes the following recommendations. First, instead of launching a large rebuilding program, the Department of Archeology should start the repair and retrofit process by conducting pilot studies. The learning from these pilot studies should be incorporated to a larger program that begins after these pilot projects. Second, repair and retrofit guidelines and standards need to be developed and should consider effects of future earthquake shaking. Third, testing of traditional materials is warranted to ensure quality rebuilding.

Research studies need to be done to better understand the performance of the damaged heritage sites, and to protect heritage sites from future earthquakes. For example, strong motion instruments should be installed at major heritage sites to help improve understanding of behavior of the structures in the earthquakes. Analytical modeling and shake table testing of repair and retrofit solutions is also recommended.

More studies needs to be done on the underlying reason of good performance and bad performance of the monuments. Geological study mainly in Pashupatinath and Nyatapola area needs to be done to verify the good performance of these temples with respect to the soil characteristics. Foundations of tiered temples especially those having wide plinth base need to be studied in detail. These studies are necessary to verify the effectiveness of traditional technology and material.

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CHAPTER 8
EMERGENCY RESPONSE

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Acknowledgements:

Special thanks are given to the Chief District Officer and Local Development Officer of Dolakha District and the Chief Executive Officer of Bhimeswor Municipality for cooperation during the field visit; NSET for coordination, logistics, and linkages to local individuals and organizations in Nepal; EERI virtual team collaborator Jennifer Lazo for assistance with reconnaissance photos; and the people in the affected areas who shared their insights.

This section of the EERI report is mainly focused on the emergency response efforts for saving lives. It covers the immediate response to the earthquake made by individuals, local communities, the national authorities, and international communities, including search and rescue, medical support, information and communication, food and shelter, and transportation. It also covers postearthquake safety evaluation, barricades, and shoring for damaged buildings. The chapter concludes with recommendations for future emergency response in Nepal.

8.1 INITIATIVES FOR EMERGENCY PREPAREDNESS AND RESPONSE IN NEPAL

In recent years, there have been several initiatives in Nepal regarding earthquake preparedness and response. The oldest disaster management guidance is provided by the Natural Calamity Relief Act 1982, which focuses primarily on response and relief activities after disasters rather than preparedness activities. A second document published by the Ministry of Home Affairs (MOHA, 2009), called the National Strategy for Disaster Risk Management (NSDRM), provides strategic direction addressing all phases of disaster management. Lastly, the newest document guided by the 2009 NSDRM, called the National Disaster Response Framework (NDRF), was prepared and approved by the Government of Nepal in 2013 (MOHA, 2013). The NDRF identifies the roles and responsibilities of the Government and nongovernmental stakeholders in the country. The NDRF has also developed a coordination mechanism among the national and international actors in case of emergency, as shown in Figure 8-1.

In 2009, the Government of Nepal established the National Emergency Operation Center (NEOC) under the Ministry of Home Affairs (MOHA). The NEOC is led by undersecretary of Disaster Management Division of MOHA. NEOC is responsible for coordination and mobilization of emergency operation activities at the national level. The NEOC has developed a Standard Operation Procedure and has a system to test it periodically. Importantly, all security forces of Nepal—namely the Nepalese Army, Nepal Police and Armed Police Force—have established separate disaster management sections with on-call responders within their organizations. Within Kathmandu Valley, the government has identified and mapped potential evacuation sites in case of major earthquake (KVDA, 2015).

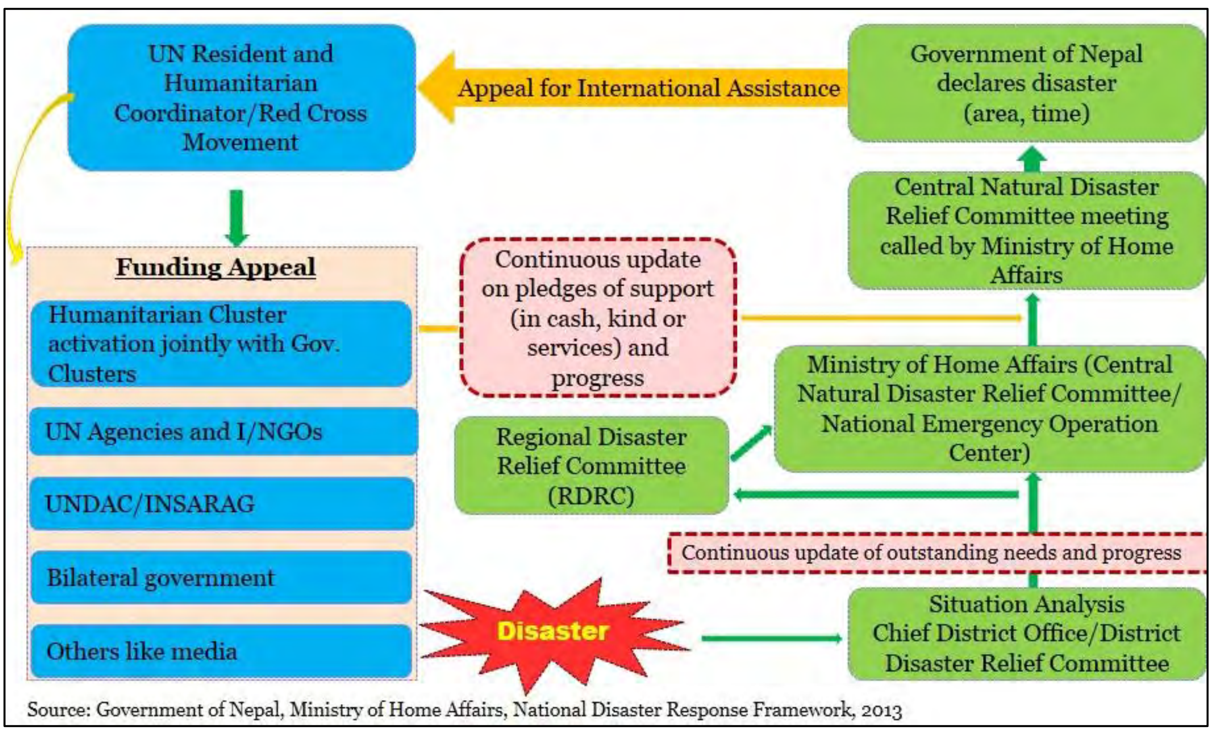


Figure 8-1. The Government of Nepal's National and International Emergency Coordination Mechanism (source: MOHA, 2013).

While both Government and nongovernment organizations have spent recent years raising awareness, mitigating earthquake risk, and building capacity for emergency response, many of the systems and procedures mentioned above are quite new and have undergone limited testing and review.

8.2 RESPONSE TO GORKHA EARTHQUAKE

As indicated in the NDRF and SOP, the NEOC was immediately activated after earthquake and was operated at Level 4, the highest level of activation. All the relevant authorities, including the acting Prime Minister and Home Minister, Chief Secretary, Secretary of the Ministry of Home Affairs (MOHA) and security chiefs, met at the NEOC for the first emergency meeting. The Central Command post was established and all the security forces were instructed to be mobilized for search and rescue operation. In a following meeting with the Central Natural Disaster Relief Committee (CNDRC) and the cabinet, the Government of Nepal decided to declare a state of emergency in all districts impacted by the earthquake and appeal for international assistance. All chief district officers were instructed to call emergency meetings and mobilize for emergency response in their respective districts.

8.2.1 Response Insights from Discussions with Citizens in Impacted Districts

The EERI team visited several communities impacted by the earthquake to better understand how Nepal's citizens responded to the earthquake (Figures 8-2, 8-3, and 8-4). The citizens interviewed often indicated that community members were the first responders to help others in distress. They responded spontaneously to the situation though they did not have any formal training or equipment in the villages. Several indicated that they had heard some tips to be followed during an earthquake such as "Drop, Cover, and Hold On" via radio, TV, and school children, but most found that they could not interpret these tips properly. In some cases, it was reported that when members of their community had tried to follow the tips, people were injured and/or victims were found dead underneath furniture in collapsed buildings. Research is currently underway to more carefully assess what specific behaviors and actions lead to casualties, so that experts can better understand if these types of reports are directly related to specific safety actions or are coincidental. The team also heard reports from individuals who indicated that they came out of structures during and/or immediately after shaking and survived, but they did not know where to go after they exited the structure. Most could not identify the difference between relatively safe places and unsafe places within their buildings or neighborhoods.

(a) (b)

Figure 8-2. (a) An old man sharing experiences of earthquake in Bhorle, Dolakha (photo: Ganesh Kumar Jimee), and (b) An interview with a survivor of 1934 earthquake, Chautara, Sindhupalchowk (photo: Kishor Jaiswal).

Figure 8-3. Displaced people resettled just at the corner of the road, Jhingati, Dolakh (photo: Ganesh Kumar Jimee).

Figure 8-4. An old woman (pictured bottom right) in Chalnakhel, Kathmandu said, "Luckily, I could come out of my home, but I had no idea where to go then," (photo: Ganesh Kumar Jimee).

8.2.2 Search and Rescue (SAR)

In Kathmandu Valley and some other urban areas, there have been some initiatives by different organizations such as Nepal Red Cross Society and National Society for Earthquake Technology (NSET) to train community members as first responders; however, such activities are limited in rural villages. Many rural villages have no trained responders or prepositioned equipment, therefore, community members spontaneously worked to rescue victims and saved many lives using traditional knowledge and locally available tools and equipment (Figure 8-5). Further, these community members played crucial roles when the professional responders arrived at the scene, by providing information, assisting in search and rescue, and supporting logistical arrangements appropriate to the local context.

(a) (b)

Figure 8-5. (a & b) Images of community responders (photos: Ganesh Kumar Jimee).

On April 25, 2015, all security forces mobilized responders within two hours of earthquake (Figure 8-6a). All security forces of the Government of Nepal (namely the Nepalese Army, Nepal Police, and Armed Police Force Nepal) have responders trained in Medical First Response (MFR), Collapsed Structure Search and Rescue (CSSR), Water Rescue, and Fire Fighting with some SAR equipment. As of May 26, the Nepalese Army had mobilized 66,000 responders, the Nepal Police had mobilized 41,776 responders, and the Armed Police Force had mobilized 24,775 responders (MOHA, May 26, 2015). Despite their quick response, the immediate reach of these official SAR efforts by the government was limited to places nearby their operation centers, and primarily focused in urban areas.

Fortunately, the only international airport into Nepal, Tribhuvan International Airport, was functional, and the major roads had limited damage allowing the international SAR teams to arrive in Nepal quickly after the earthquake (Figure 8-6b). There were 76 international SAR teams with 4,316 responders arriving from Day 1 to 6, as shown in Figure 8-7 (Nepalese Army, 2015).

(a) (b)

Figure 8-6. (a) National Responders, and (b) International Responders (photos: Ganesh Kumar Jimee).

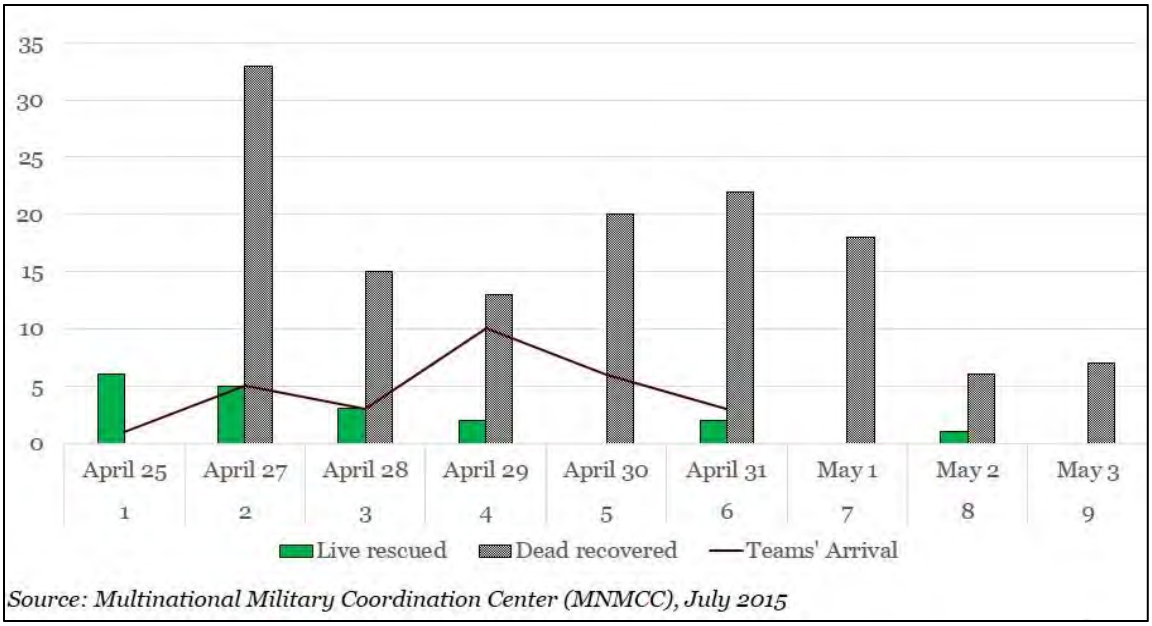


Figure 8-7. Graph showing arrival of international SAR teams and their operational success (source: MNMCC, 2015).

Due to a variety of different reasons such as remote locations, damaged roads, difficult terrain, and adverse weather, the arrival time of SAR responders varied in the impacted regions. This delay in SAR response was reflected in the success rate of saving lives. Out of 22,326 injured people, 19 victims were rescued by international SAR teams, 4,420 victims were rescued by national teams, and the remaining 17,887 live victims were rescued by either community responders and/or by self-rescue. Similarly, out of 9,256 deaths, 135 were recovered by international teams, 2,133 by national teams, and 6,988 by community members. These statistics are shown in Figure 8-8.

These statistics indicate the need for increasing the capacity of community responders by ensuring that community members have minimum search and rescue skills, and prepositioning equipment in strategic locations for rescue operations. They also suggest the need for enhancing the capacity of national responders in terms of number of responders, skill, and equipment.

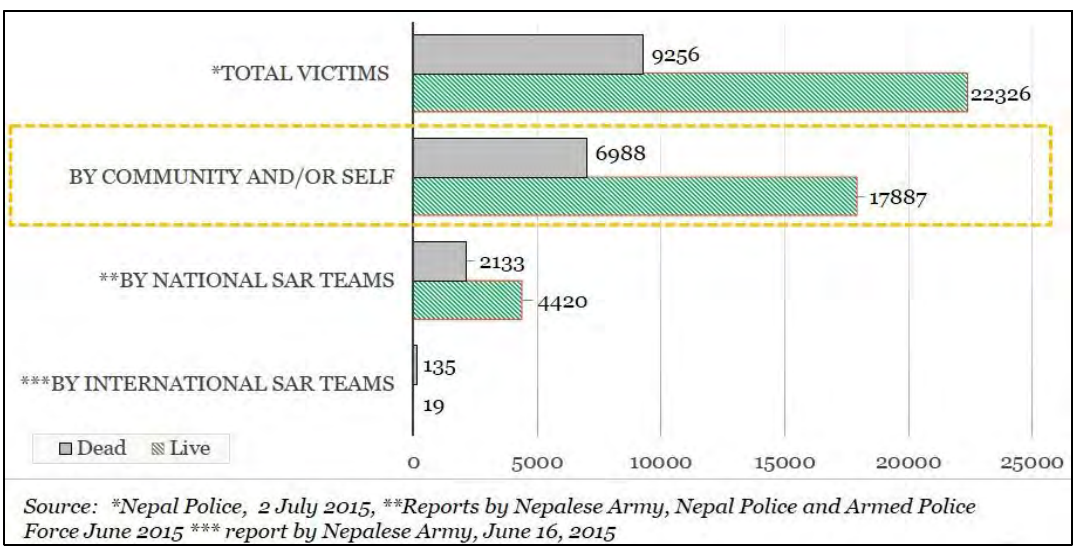


Figure 8-8. Extricated Victims and Recovered Dead Bodies by Different SAR Teams (source: MNMCC, 2015).

8.2.3 Emergency Shelter and Aid Distribution

Following the earthquake, an immediate need in most impacted areas was shelter. Due to the high numbers of buildings that collapsed and/or were heavily damaged, many people were unable to reoccupy their evacuated buildings. Moreover, due to frequent aftershocks, people who lived in buildings with minor damage and/or no damage were often too afraid to reoccupy their homes. Also, there was scarcity of tents and tarpaulins in the local markets for erecting emergency shelter. On the first night following the earthquake, very few people were able to create emergency shelters of their own, so many people spent whole night under the open sky near their damaged buildings. A limited number of individuals were also able to obtain some temporary shelter structures provided by local organizations. On the second day following the earthquake, the Government and nongovernmental organizations started to distribute tents and tarpaulins as emergency shelters in affected areas; however, these efforts were not very organized and were insufficient to fulfill the demand (Figure 8-9a). This high demand for tents and tarpaulins continued throughout the first week. After that time, many people were demanding temporary shelter materials like corrugated galvanized iron (CGI) sheets and/or more durable roofing materials (Khazai et al., 2015).

(a)

(b)

Figure 8-9. (a) Emergency shelter next to damaged building in Bagdol, Lalitpur, and (b) Emergency shelter using salvaged materials in Chalnakhel, Kathmandu (photos: Ganesh Kumar Jimee).

The United Nations shelter cluster system (also described in Chapter 9, Section 9.6) was activated to coordinate shelter related activities in affected districts through the District Disaster Relief Committee (DDRC). The Government of Nepal provided 5,000 Nepalese Rupees (NPR) per totally collapsed building and 3,000 NPR per partially damaged building (MOHA, 2015) as immediate support. The Government also instituted a ‘One Door Policy’ to distribute all relief materials through Government authorities, but it was not effective. Many organizations, individual donors, and volunteer groups independently provided shelter materials and supported displaced people who needed to construct emergency shelters. Very few people stayed in the formal group shelters. It was observed that most of the affected people constructed emergency shelters near their damaged buildings and property using salvaged materials (Figure 8-9b). The major problem in these shelters was of lack of water, food, and sanitation.

Food in many homes was buried under the collapsed buildings resulting in the scarcity of food in the impacted areas. Some people living in temporary shelters had evacuated from undamaged buildings and buildings with minor damage due to frequent aftershocks and were too afraid to go back into these structures to get food. Many villages were separated from nearby market centers due to damaged roads which made it difficult to supply food and other relief items to people in these rural villages. Even in the district headquarters, many shops were either badly damaged or closed due to the earthquake. The Government provided 40,000 NPR per death and 2,000 NPR per family for immediate food support (MOHA, 2015). The EERI team was pleased to discover that people in some areas in Kathmandu were prepared with “Earthquake Go Bags” containing some food and other emergency supplies. These bags helped them more easily survive for the first one to two days. It was learned from discussions with affected people that there were many organizations in the districts distributing food and other relief materials, but in some cases the effort was viewed as poorly organized and sometimes deprived the people in real need.

Many volunteers from different Government and nongovernment organizations were mobilized to provide medical support. The National Health Emergency Operation Center (HEOC) under the Ministry of Health and Population coordinated the international medical response teams and deployed in affected areas. There were more than 1,400 international medical responders from 78 countries who responded to the earthquake (MOHA, 2015).

8.3 POSTEARTHQUAKE SAFETY EVALUATION

By the time of the EERI team's visit about six weeks after the April 25 mainshock and about three weeks after the large May 12 aftershock, 60,000 postearthquake safety evaluations had been done. Many organizations were involved, including the Nepal Engineer's Association (NEA). NEA has a large series of valuable resources related to evaluations on their website (NEA, 2016). Other NGOs were involved and some utilized volunteer foreign engineers. In most cases, only government buildings received an official posted placard or tag. In other cases, though a placard was not placed, evaluators discussed their findings with owners, residents, and tenants.

Various types of placards were observed. At the check-in desk of the hotel where the EERI team stayed while they were in Kathmandu, the building had minimal damage, and there was a framed copy of a placard the hotel had received. It is shown in Figure 8-10. The inspecting agency was identified as the Department of Tourism. The level of technical expertise used by the Department of Tourism and the extent of structures they tagged are not known, but relatively few buildings are assumed to have been tagged by this agency.

Figure 8-10. Placard at hotel front desk in Kathmandu (photo: Bret Lizundia).

In a government office building in Chautara, Sindhupalchowk, a red "UNSAFE" placard had been placed on a building with substantial damage. The placard is shown in Figure 8-11, and it is similar to those in ATC-20 (1989). ATC-20 has three categories: UNSAFE (colored red), RESTRICTED USE (colored yellow), and INSPECTED (colored green). The Department of Education performed evaluations of school buildings. Figure 8-12 shows an example of a lightly damaged school in Sankhu, one of the suburbs of Kathmandu. It received a green tag. It is quite attractive and resembles a flag. In Chautara, postearthquake evaluations had been performed prior to the EERI visit for the buildings along the main street of the town. Many were heavily damaged. Evaluators had spray painted green, yellow, or red dots near ground story entrances of the building. Figure 8-13 shows two adjacent buildings. The severely leaning building on the left has a red spray paint mark; the less damaged building on the right has a yellow spray paint mark.

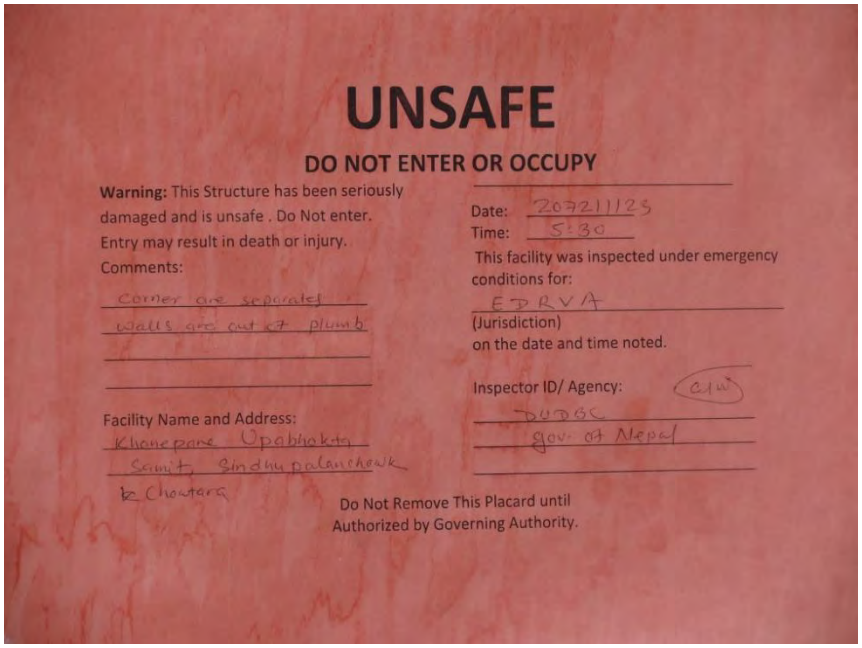


Figure 8-11. UNSAFE placard on heavily damaged government office building in Chautara, Sindhupalchowk (photo: Hemant Kaushik).

Figure 8-12. School building with a green tag by the Department of Education in Sankhu (photo: Hemant Kaushik, annotations: Bret Lizundia).

Figure 8-13. Spray painted postearthquake safety evaluation results of buildings on the main street in Chautara, Sindhupalchowk (photo: Hemant Kaushik, annotations: Bret Lizundia).

The National Society for Earthquake Technology (NSET) and the Department of Urban Planning and Building Construction (DUDBC) had developed guidelines regarding postearthquake safety evaluation prior to the Gorhka Earthquake (NSET/DUDBC, 2009). The guidelines draw from ATC-20 (1989), ATC-20-1 (2005) and FEMA 306 (1998), but also have information specific to Nepal. When the ATC-20-1 update was prepared, the LIMITED ENTRY category was changed to RESTRICTED USE. The RESTRICTED USE category was used to restrict use in certain areas of the building which had been damaged and pose a significant hazard in a future aftershock. A RESTRICTED USE tag is shown in Figure 8-14. The three categories used by the NSET/DUDBC guidelines are summarized in Table 8-1. While the INSPECTED and UNSAFE category definitions in NSET/DUDBC (2009) are similar to those in ATC-20-1, the yellow category is somewhat different. It indicates entry is only by the owner, not others, and only for emergency purposes, not on a permanent basis. We observed many buildings with yellow spray painted dots in Chautara that were continuing to be occupied. Figure 8-15 shows a shop selling fruits and vegetables that remained open to the public despite the yellow tag. Residents indicated evaluators had explained to meaning of the yellow dot, but the residents chose to keep the store open due to the need for income. They did not sleep in the residential portion upstairs at night, but rather in a nearby tent. We understood this approach was not uncommon while large aftershocks continued.

RESTRICTED USE

Caution: This structure has been inspected and found to be damaged as described below:

Entry, occupancy, and lawful use are restricted as indicated below:

☐ Do not enter the following areas:

☐ Brief entry allowed for access to contents:

☐ Other restrictions:

Facility name and address:

Date

Time

(**Caution:** Aftershocks since inspection may increase damage and risk.)

This facility was inspected under emergency conditions for:

(Jurisdiction)

Inspector ID / Agency

Do Not Remove, Alter, or Cover this Placard until Authorized by Governing Authority

Figure 8-14. ATC-20-1 RESTRICTED USE yellow tag (source: ATC-20-1, 2005).

Table 8-1. NSET/DUDBC Guideline postearthquake safety placard criteria (source: NSET/DUDBC, 2009)

Posting Classification	Color	Description
INSPECTED	**Green**	No apparent hazard found, although repairs may be required. Original lateral load capacity not significantly decreased. No restriction on use or occupancy
LIMITED ENTRY/Restricted Use	**Yellow**	Dangerous condition believed to be present. Entry by owner permitted only for emergency purposes and only at own risk. No usage on continuous basis. Entry by public not permitted. Possible major aftershock hazard
UNSAFE	**Red**	Extreme hazard may collapse. Imminent danger of collapse from an aftershock. Unsafe for occupancy or entry, except by authorities.

Figure 8-15. Occupied yellow-tagged store in Chautara, Sindhupalchowk (photo: Jan Kupec, annotations: Bret Lizundia).

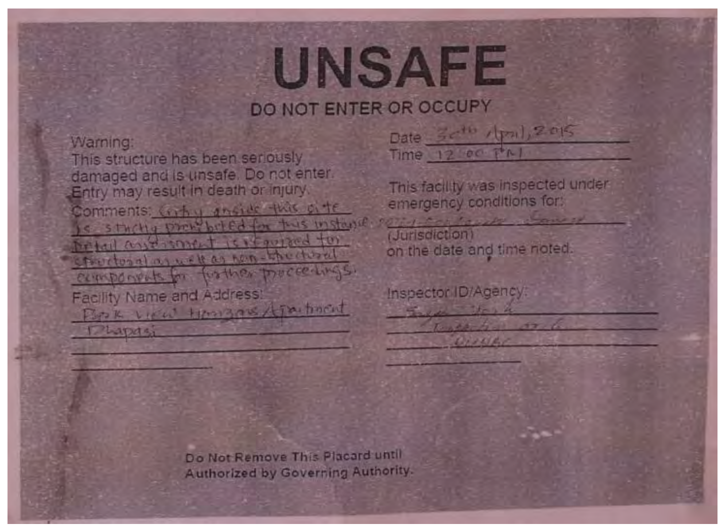
The language and intent for red-tagged UNSAFE structures is similar in the NSET/DUDBC guidelines and in ATC-20-1. Such structures are not to be occupied. Figure 8-16a shows a heavily damaged building in Chautara that was posted with a red spray painted dot. It was vacated. However, we did see some with red dots that were still occupied. Figure 8-16b shows an example. Enforcement of tagging status was not observed in Chautara or typically in other areas of the country. An exception was a heavily damaged apartment complex in Dhapasi, a suburb of Kathmandu. These reinforced concrete frame buildings with masonry infill at the top of a hill are shown in Figure 8-17a and had been tagged UNSAFE and vacated. Security guards enforced the closure. The tag posted at the closed gate is shown in Figure 8-17b.

(a)

(b)

Figure 8-16. (a) Vacated red-tagged structure in Chautara, Sindhupalchowk (photo: Bret Lizundia), and (b) Occupied red-tagged structure in Chautara, Sindhupalchowk (photo: Hemant Kaushik).

(a)



(b)

Figure 8-17. (a) Vacated red-tagged apartment building with security guards in Dhapasi, and (b) UNSAFE placard at Dhapasi apartment building with text stating, "Entry inside this site is strictly prohibited for this instance. Detailed assessment is required for structural as well as nonstructural components for further proceedings." (photos: Hemant Kaushik).

The NSET/DUDBC guidelines were used by many of the organizations performing evaluations. They contain both rapid and detailed evaluation assessment methods. At the time of the EERI visit, the vast majority of evaluations that had been conducted were rapid assessments. Figure 8-18 shows the Rapid Evaluation Safety Assessment Form. It is somewhat similar to the form in ATC-20-1. The NSET/DUDBC guidelines have some example figures to help evaluators with determining the appropriate tags. Figure 8-19 shows an example. A somewhat similar but much more detailed approach was taken for the ATC-20-1 update for Bhutan (ATC, 2014).

Rapid Evaluation Safety Assessment Form

Inspection

Inspector ID: ______ Inspection date and time: ______ ☐ AM ☐ PM

Organization: ______ Areas inspected: ☐ Exterior only ☐ Exterior and interior

Building Description

Building Name: ______ Address:

District: ______

Building contact/phone: ______ Municipality/VDC : ______

Approx. "Footprint area" (sq. ft): ______ Ward No: ______ Tole: ______

Type of Construction

☐ Adobe ☐ Stone in mud ☐ Stone in cement ☐ Brick in cement ☐ Wood frame

☐ Bamboo ☐ Brick in mud ☐ Brick in cement ☐ R.C frame ☐ Others: ______

Type of Floor

☐ Flexible ☐ Rigid

Type of Roof

☐ Flexible ☐ Rigid

Primary Occupancy:

☐ Residential ☐ Hospital ☐ Government office ☐ Police station

☐ Educational ☐ Industry ☐ Office Institute ☐ Mix

☐ Commercial ☐ Club ☐ Hotel/Restaurant ☐ Others: ______

Evaluation

Observed Conditions:	Minor/None	Moderate	Severe
➢Collapsed, partially collapsed, or moved off its foundation	☐	☐	☐
➢Building or any story is out of plumb	☐	☐	☐
➢Damage to primary structural members, cracking of walls, or other signs of distress present	☐	☐	☐
➢Parapet, chimney, or other falling hazard	☐	☐	☐
➢Large fissures in ground, massive ground movement, or slope displacement present	☐	☐	☐
➢Other hazard (Specify) e.g tree, power line etc:	☐	☐	☐

Estimated Building Damage (excluding contents)

☐ None

☐ 0-1%

☐ 1-10%

☐ 10-30%

☐ 30-60%

☐ 60-100%

☐ 100%

Comments: ______

Posting Choose a posting based on the evaluation and team judgment. Severe conditions endangering the overall building are grounds for an Unsafe posting. Localized Severe and overall Moderate conditions may allow a Restricted Use posting. Post INSPECTED placed at main entrance. Post RESTRICTED USE and UNSAFE placards at all entrances.

☐ **INSPECTED** (Green placard) ☐ **RESTRICTED USE** (Yellow placard) ☐ **UNSAFE** (Red placard)

Record any use and entry restrictions exactly as written on placard: ______

Further Actions Check the boxes below only if further actions are needed.

☐ Barricades needed in the following areas:

☐ Detailed evaluation recommended: ☐ Structural ☐ Geotechnical ☐ Other ______

Comments: ______

Figure 8-18. Rapid Evaluation Safety Assessment Form (source: NSET/DUDBC, 2009).

Figure 8-19. Rapid Evaluation Safety Assessment Form guidance photos (source: NSET/DUDBC, 2009).

The NSET/DUDBC Detailed Evaluation differs from that in ATC-20-1. The Detailed Evaluation does not have placard status. There are five “Damage Grades” and retrofit/demolition recommendations. Images are used to illustrate the damage grades. Damage Grade 1 is the equivalent of a green tag. Damage Grades 4 and 5 are for partially or totally collapsed structures that would be red-tagged. Damage Grades 2 and 3 cover the wide spectrum between Damage Grade 1 and Damage Grade 4. Figure 8-20 shows an excerpt of the definitions from Damage Grades 2 and 3. Evaluators told the EERI team that more detail and more examples for the Damage Grade 2 and 3 categories would be helpful.

Damage Grade 2

	
Thin cracks in many walls, falling of plaster in last bits over large area, damage to non-structural parts like chimney, projecting cornices; The load carrying capacity s not reduced appreciably.	Architecture repairs needed, Seismic strengthening advised.

Damage Grade 3

Large and extensive cracks in most walls, roof tiles detach, tilting or falling of chimneys, failure of individual non-structural elements such as partition/ gable walls. Load carrying capacity of structure is partially reduced.	Cracks in wall need grouting, architectural repairs required, Seismic strengthening advised

Figure 8-20. Detailed Evaluation Damage Grade definitions (source: NSET/DUDBC, 2009).

8.4 BARRICADES AND SHORING

At the time of the EERI team’s visit, relatively few barricades had been established to cordon off dangerous areas and buildings and to protect pedestrians from falling hazards.

In California, the California Building Officials (CALBO) developed a document to provide guidance for barricades, cordons, and shoring based on observations following the 2011 and 2012 earthquakes in Christchurch, New Zealand. The *Interim Guidance for Barricading, Cordoning, Emergency Evaluation, and Stabilization of Buildings with Substantial Damage in Disasters (CALBO, 2013)* guide recommends setting a preliminary soft barrier for fencing at a horizontal offset distance of at least 1.5 times the height of a damaged structure in typical situations. These guidelines are recent, not mandatory, and not well publicized, and typically each jurisdiction approaches barricading differently following an earthquake. In most locations in Nepal, the streets are narrower than the height of the buildings adjacent to the street, so a 1.5 horizontal to 1.0 vertical criterion would lead to preventing access to the street entirely, and buildings on one side could still pose a risk to the adjacent or opposing buildings. Figure 8-21 shows a leaning building with a ground story collapse next to the main street. Figure 8-22 shows a reinforced concrete frame building with masonry infill where the infill has fallen out at the ground story, and damage to the frame poses a risk of the structure falling into the street in an aftershock. There was no barricade, and pedestrians were walking next to the damaged building.

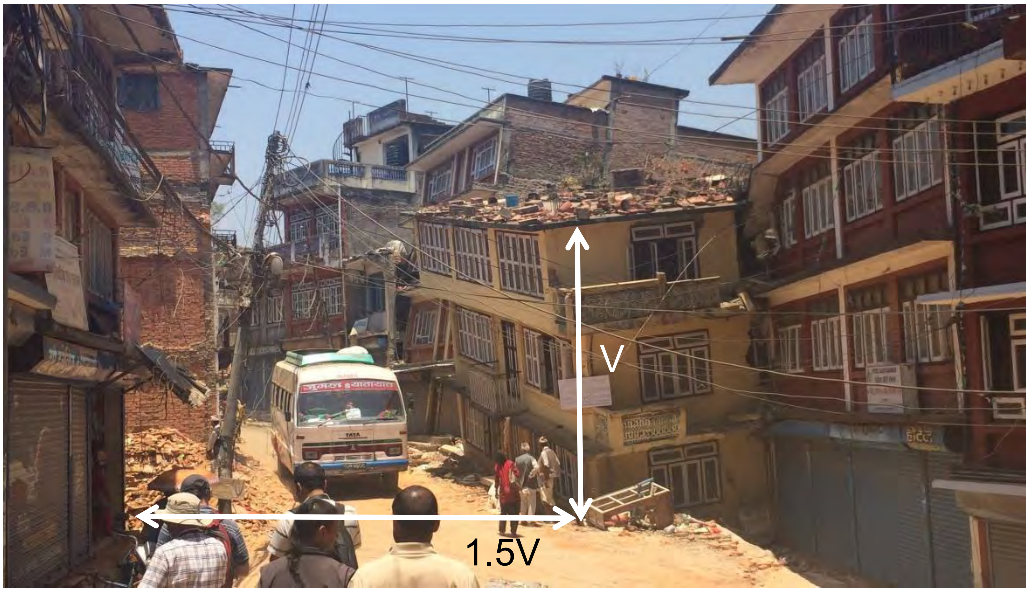


Figure 8-21. Leaning building with ground story collapse next to main street in Chautara, Sindulpalchowk (photo: Jan Kupec, annotations: Bret Lizundia).

Figure 8-22. Damaged reinforced concrete frame with masonry infill in Chautara (photo: Bret Lizundia).

In some towns, setting a barricade or cordon around areas with heavily damaged buildings, such as was done in the 2010 Christchurch New Zealand Earthquake or the downtown area of Santa Cruz in the 1989 Loma Prieta, California Earthquake, would have effectively restricted access to the vast majority of the town, simply because of the scale of damage and devastation. Instead, recovery efforts focused on debris removal in the streets first to clear a pedestrian path and then a path for vehicles, then adding shoring to damaged buildings, and then beginning demolition of heavily damaged buildings. As a result, pedestrians and vehicles would often pass directly in front of or under heavily damaged structures while large aftershocks were still frequent. There were a few notable exceptions that the EERI team observed. In Kathmandu's Durbar Square, a small temporary guardrail was placed to keep pedestrians as far away from the damaged heritage structures as possible. This is shown in Figure 8-23. There were some guards lightly enforcing the barricading as well. Some of the structures adjacent to the pedestrian paths were damaged, though less than the heritage structures. Given the Durbar Square's cultural significance and importance to tourism, efforts were made to give viewing access to the heritage structures from across the guardrail as soon as practical.

Figure 8-23. Light "barricade" guardrail installed in street surrounding damaged heritage structures in Kathmandu's Durbar Square (photo Bret Lizundia).

By the time of the EERI visit, shoring had been installed at many structures including both temples and buildings. Typically, wooden posts of about 100 mm by 100 mm were used. Figure 8-24 shows a shoring at the lower tier of two temples in Kathmandu's Durbar Square. Figure 8-25a shows a heavily damaged masonry structure in Bhaktapur with a lost façade on one side and a leaning façade on the other side. Figure 8-25b shows bracing of a lightly damaged masonry façade adjacent to Kathmandu's Durbar Square. Figure 8-26a shows a similar approach next to Patan's Durbar Square. Note the long length of the shoring braces; they are already sagging under self weight in a few cases. The capacity of the long braces to resist buckling under compression will be limited. Capacity, though, is likely further limited by the connection of the shoring post to the ground, which is often just a simple peg such as shown in the lower photo of Figure 8-26a. By inspection, such braces will have only a fraction of the capacity needed to resist loading in a damaging aftershock.

Figure 8-24. Shoring of bottom tier of temple in Kathmandu Durbar Square (photo: Bret Lizundia).

(a) (b)

Figure 8-25. (a) Heavily damaged brick masonry bearing wall structure with light shoring in Bhaktapur (photo: Bret Lizundia), and (b) shoring of a lightly damaged masonry building adjacent to the street across from Kathmandu Durbar Square (photo: Bret Lizundia).

(a)

Figure 8-26. (a) Shoring of buildings next to Patan Durbar Square with detailed view of a typical shorting post base (photos: Bret Lizundia), and (b) Bracing buildings against one another above a narrow street in Bhaktapur (photo: Bret Lizundia).

Due to the narrow streets and alleys in older areas of many towns, it is not always possible to create an effective bracing angle with shoring. Figure 8-26b shows the approach that was taken in some areas of bracing buildings against one another over the street level. The alley passageway was not cordoned off, nor was scaffolding with protective covers used in case small pieces of masonry were to fall on the alley below.

8.5 RECOMMENDATIONS

The following recommendations should be considered and implemented to improve emergency response after future earthquakes in Nepal.

- Search and Rescue (SAR) capacity enhancement is needed at a variety of levels. Professional skills are needed at the national level for national security forces personnel, while minimum lifesaving skills are also needed for community volunteers at a large scale.
- Prepositioning of SAR equipment should be done in advance of disasters. Advanced SAR equipment sets should be placed in all districts for professional responders and standard SAR equipment should be placed in all villages for use by community responders.
- Review, testing, and updating of existing emergency response plan documents should occur at all levels and in communities of all sizes.
- Efforts to conduct hazard and resource mapping should take place in all villages with the involvement of local people.
- Further research is needed to identify the optimum safe behavior to be performed by individuals in the context of Nepal building types, culture, and environment.
- For postearthquake safety evaluations, coordination between different organizations and quality assurance is challenging, the understanding of the red and yellow tag restrictions may not be clear to either evaluators or the public, and increasing the specificity and range of examples in guideline documents will be helpful.
- Realistic guidelines and effective implementation are need for barricades, cordoning, and shoring.

8.6 REFERENCES

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CHAPTER 9
SOCIAL, CULTURAL, AND PSYCHOLOGICAL IMPACTS

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Acknowledgements:
Special thanks are given to co-interviewers Rubina Awale, Shree Niwas Khanal, and Sauharda Rai, and virtual collaborators Melissa Tucker and Katy Wall.

Textual Note:
Readers should be aware that issues associated with the reconstruction are constantly evolving, and the information included in this chapter is accurate through November 2015.

9.1 INTRODUCTION

In this chapter, we summarize social, psychological, and cultural factors with implications for disaster preparedness and rebuilding in the aftermath of the April 25, 2015 earthquake in Nepal. In the introduction, we describe our rapid assessment and sampling methods. In the remainder of the chapter, we then go on to discuss findings with regard to disaster attributions, mental health and coping, social support/cohesion and conflict, remittances, remuneration and livelihoods, relief aid mechanisms, socio-political considerations (including the history of civil war and issues of governance), and challenges and opportunities associated with ethnic and linguistic diversity. We conclude with a summary and suggestions for future research.

9.1.1 Rapid Assessment Methods

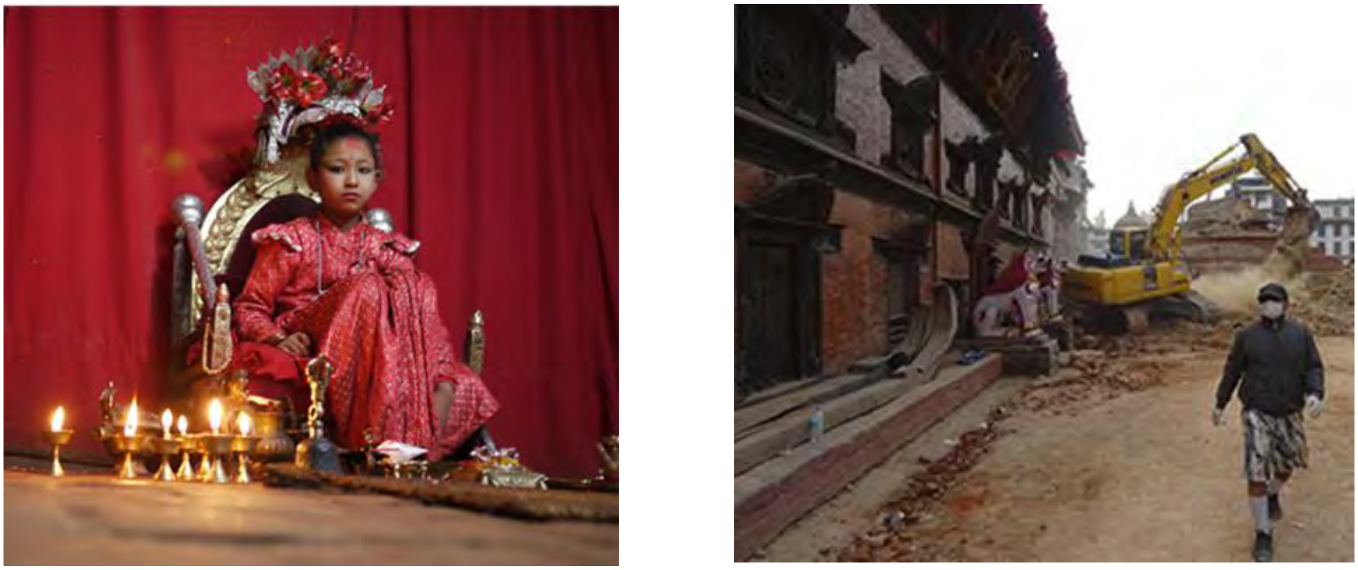
In the context of a rapid assessment, semi-structured interviews were conducted on a daily basis by Courtney Welton-Mitchell and Rubina Awale. Shree Niwas Khanal and Sauharda Rai also assisted with interviews one day each. A total of approximately 80 interviews were conducted with community members, government officials, and relief agency staff in the Kathmandu, Lalitpur, Bhaktapur, Kavre Palanchok, and Sindhupalchok districts during the period from May 31 to June 8, 2015 (see Chapter 1, Figure 1-11). Interview times ranged from about five minutes to over an hour, averaging approximately 20-25 minutes. A systematic sampling process was not used for these interviews, but instead the interviewers obtained a convenience sample based primarily on who was available and willing to speak with us as we walked through various communities surveying the damage. As a result, the views of community members in relatively accessible areas are over-represented here. Every attempt has been made to accurately reflect the views of those with whom we spoke, including selecting representative quotes instead of emphasizing atypical or uncommon reactions. Additional information has been pulled from secondary sources for this section including news articles and government and agency reports, with updates based on the current situation in Nepal through November 17, 2015. Finally, in putting together this chapter, the author has also drawn on experience over many years working with humanitarian agencies in Nepal and involvement with two ongoing grant-funded disaster mental health intervention research projects for (1) 240 earthquake survivors in Bhaktapur district, Kathmandu Valley, and (2) 480 flood survivors in far-western Kailali district.

9.2 DISASTER ATTRIBUTIONS

After exchanging introductions and requesting consent to be interviewed, we often started by asking community members: “What do you think caused the earthquake?” Many people, especially in rural areas, indicated that the earthquake had occurred because people have lost the path of religion/spirituality or dharma, and this has made the Gods angry. Some went on to explain that the past deeds (karma) of some community members were to blame for the earthquake, and even went so far as to indicate that this may explain why some died while others were spared. Other community members stated that certain buildings were damaged due to a lack of proper site selection and preparation with Brahmin priests. Some people shared their beliefs that the reason certain structures such as the Palace of the Kumari (“living goddess”) in Kathmandu’s Durbar Square and Pashupatinath Temple complex in Kathmandu were still standing was because the Gods chose to protect these structures (Figures 9-1 and 9-2). Still others referred to the ‘movement of snakes’ under the earth causing the earthquake, presumably making reference to Sheshnag, the hundred-headed snake that holds Lord Vishnu and is said to cause earthquakes when it moves one of its many heads (Narayani, 2015). Of course, some community members also indicated that energy is released when rocks move or slip underground. This explanation appeared to be more common among younger and educated participants in urban areas.

After asking about attributions, we typically asked community members if they believed they were at risk for additional disasters in the near future, including earthquakes, aftershocks, and/or landslides. Many people indicated yes, stating that they believed they were at very high risk and felt “very afraid” about future disasters. Realizing that nearly everyone we spoke with perceived their risk of future disaster as high—at least at the time of these interviews just weeks after the earthquakes—we were curious to know if people were engaged in any type of disaster preparedness in an attempt to mitigate risk.

Some respondents indicated they were not doing anything to prepare for future disasters. However, other community members indicated that they were involved in some risk mitigation strategies. For example, a few people explained that they will repair or retrofit existing structures, or build new structures, working in consultation with local architects or engineers. A handful of others said they plan to store extra food and water, keep documents in a safe place, and discuss what to do in the event of a disaster with their family members, including putting in place evacuation plans. Many of the people we interviewed, representing a variety of ethnic and caste groups from both rural and urban areas, told us about spiritual/religious practices (including 'puja') in response to questions about risk mitigation. Puja is the act of showing reverence to a god, a spirit, or another aspect of the divine, through offerings such as fruit, rice, flowers, prayers, and/or songs. In fact, we heard quite a bit about a specific ceremony known as "Chyama Puja" which loosely translates to mean "forgiveness ceremony." In addition to those who had already performed the ceremony designed to ask forgiveness from the Gods, others told us that they planned to hold the ceremony in the coming days. One resident in a community where 250 households had participated in the ceremony a few days earlier explained, "After performing the Chyama Puja, we were content; it helped; now we are less fearful of aftershocks."



(a) (b)

Figure 9-1. (a) Image of Kumari 7-year-old "Living Goddess Yunika Bajracharya" of Kathmandu Durbar Square (source: Ratna, 2015), and (b) the Kumari Palace, left side of frame, fared relatively well in the earthquake while nearby structures in Durbar Square crumbled (source: Mallet, 2015).

Figure 9-2. Pashupathinath Temple in Kathmandu is dedicated to Lord Shiva. It survived the earthquake with relatively minor damage while other historical structures of seemingly similar design were destroyed (source: Zvacek, 2015).

At times, our question about risk mitigation was met with seemingly fatalistic responses. For example, we visited a community on the outskirts of Kathmandu, at the top of the ridgeline, where most of the residential structures had been destroyed. We were told by community members that the army came through and asked them to evacuate due to landslide risk. However, most community members had already put up temporary shelters in anticipation of monsoon rains (Figure 9-3). When asked why people did not seem to be following the army's advice to relocate, one local Tamang woman explained, "No matter where you go, if it is written in your fate to die, you will die."

Figure 9-3. Woman walking along a path between destroyed residential structures, Bhimdunga VDC, Nagarjun Municipality, Kathmandu Valley. Temporary structures were erected in this community weeks after the earthquake, despite the risk of landslides (photo: Courtney Welton-Mitchell).

While this way of thinking came up across several interviews, this is not to suggest that fatalism is the whole story, that karmic explanations are the only way of understanding the earthquake, or that spiritual ceremonies are performed as a sole means of disaster mitigation. Nepal is a diverse country where many belief systems can be found. As mentioned, educated youth in urban areas tend to favor scientific explanations for the earthquake. Urban planners and engineers in Nepal have explained that Pashupatinath Temple is still standing, not because of divine intervention, but because of the building materials used (Misra, 2015). As noted in a CNN article that appeared shortly after the earthquakes in Nepal, "Some place the blame at the feet of karma – human actions that result in future consequences. But many others see earthquakes and tsunamis as amoral events, neither caused by angry deities nor visited on deserving sinners" (Burke, 2015).

Interestingly, we did not notice a pattern wherein only certain beliefs about the cause of the earthquake were associated with disaster preparedness. For example, even among those who believed that the earthquake was a result of God's Will, disaster preparedness was happening. This may in part be because stories about "Gods helping those who help themselves" are common in Nepal (among Hindus and Christians alike). We have successfully incorporated such stories in our disaster preparedness intervention research with flood and earthquake survivors in Kailali and Bhaktapur districts. In the course of this work, we have found many community members embracing a divine explanation for natural disasters while also engaging in reinforcing or modify dwellings to mitigate the potential for damage from future disasters.

9.3 MENTAL HEALTH AND COPING

We were interested in an informal assessment of the mental health and well-being of those directly affected by the earthquake. Mental health symptoms can interfere with the ability to complete daily tasks, undermining the potential for rebuilding and recovery. During interviews we asked community members about 1) psychological and psychosocial difficulties they may be experiencing in the aftermath of the earthquake, 2) top concerns or worries, and 3) whether such concerns might be interfering with their ability to perform daily tasks, including engaging in livelihood and rebuilding activities.

Although there were some notable exceptions (described later in this section), most people we spoke with reported distress of one form or another. One elderly woman, in a community where nearly all of the homes had been destroyed, stated "The people who died in the earthquake are not in any pain, but the ones who lived have to face continued suffering." Many of those we interviewed reported worry or anxiety over disruptions in the harvest, lack of livelihood opportunities, lack of resources for rebuilding, and the potential impact of the earthquake on their children's future. Some explained that feelings of hopelessness about the future were having an impact on their motivation to harvest and rebuild: "Now is the time to harvest and plant, but we are too stressed and sad…." Another indicated, "we should be planting cash crops now, but we can't make ourselves go to the field because of everything that has happened; we will lose a lot of income." Others shared intrusive memories of having been buried under rubble, explaining that it was hard for them to concentrate on anything. Countless people spoke of constant fear of another earthquake, re-experiencing in the form of the ground moving, and not being able to tell when actual aftershocks were taking place: "I always feel like the earth is moving, we are living in constant fear of another earthquake." Sleep difficulties were mentioned frequently. A few people shared concerns about an increase in alcohol use among some community members, along with an increase in interpersonal conflicts, and general irritability. We spoke to some survivors who explained that drunk community members had been making people feel nervous in some of the displaced camps. Finally, some interviewees, especially those working with children, raised concerns about the potential impact of caregiver distress on children: "When parents constantly say, 'we are going to die, there is nothing we can do, all is lost' of course children will be fearful and unable to sleep."

Although the mental health related questions we asked during informal interviews were a far cry from a more thorough standardized assessment, our findings are consistent with reports from leading mental health agencies responding to the earthquake in Nepal. International Medical Corps (IMC) and others have emphasized that earthquake-affected communities are experiencing unfulfilled basic needs, a loss of livelihood opportunities, and in some cases, a loss of traditional social networks—all contributing to psychological distress (Table 9-1). Common forms of distress emphasized by IMC in their rapid assessments weeks after the earthquakes include fear, anxiety, sadness, anger, sleep difficulties, and increased risk of suicide (IMC, 2015). Figures released by the Kathmandu Metropolitan police force within a few months of the earthquakes indicate that the suicide rate in Kathmandu Valley increased by 24 percent compared to the same two-month period the previous year. A police officer was quoted in an article in the Himalayan Times about the increase in suicides following the earthquake said "Seven persons killed themselves as they lost their mental balance due to deaths of their loved ones and damage to property in the quakes" (Himalayan Times, 2015).

Table 9-1. Results of IMC's Rapid Mental Health and Psychosocial Support Assessment, May 2015. (source: IMC, 2015)

Stressors Related to Basic Needs	Stressors Related to Livelihood	Stressors Related to Social Needs	Psychosocial Distress
• **Shelter** (e.g. lack of tents and inability to rebuild homes; monsoon season approaching) • **Physical Health and WASH** (e.g. illness due to hygiene and sanitation concerns) • **Food and Nutrition** (e.g. food insecurity and inadequate food aid in remote areas) • **Clothing and blankets** in remote villages	• **Livelihoods and livestock** lost during the earthquake and landslides • **No source of income** and resulting stress of providing for the family	• **Loss of social support systems** (e.g. family or loved ones deceased, or missing) • **Separation of loved ones** (e.g. family separation due to displacement or medical evacuation to other areas)	• **Loss and bereavement** regarding loss of loved ones and belongings • **Fear and anxiety** (e.g. that another earthquake will occur; that they will not be able to protect loved ones; frightening aftershocks) • **Sadness, hopelessness, and uncertainty** about the future; difficulty imagining how to move on, especially with monsoon season approaching • **Anger and irritability** in reaction to stressors • **Decreased sleep, appetite, and concentration,** affecting participation/ completion of daily activities • **Despair and suicide** in a number of reported cases

Finally, while Western-derived notions of psychological distress such as "depression" and "post-traumatic stress disorder" are likely still relevant in the Nepali context, it is also important to consider local idioms of distress (i.e. culturally specific indicators of distress). A Nepal-specific mental health literature review was conducted in the aftermath of the earthquake by an inter-agency committee, with the intention of supporting agencies in providing mental health and psychosocial support for earthquake survivors (IASC, 2015). The review highlighted the importance of considering culturally-specific frameworks for understanding distress. For example, it is not uncommon for some in Nepal to explain earthquake-related distress as a "wound" to the "heart-mind" or a "soul loss." Given the diversity of presenting symptoms, belief systems, and ethnic groups in Nepal, it is advisable to involve multiple stakeholders—including family members/peers, traditional healers (shaman or priests), psychosocial workers and/or mental health clinicians—in supporting the process of recovery for distressed earthquake survivors.

A growing disaster psychology literature points to the importance of considering both acute stressors, such as the actual earthquake, and ongoing/chronic stressors in mental health outcomes following natural disasters. Typical chronic stressors for disaster survivors can include a lack of adequate shelter and food, and uncertainty about other resources needed to reestablish a sense of 'normalcy.' This appears to be the case in Nepal as well. Himalmedia conducted a nationwide public opinion survey in Nepal in July 2015 involving 3,500 respondents in 35 districts (Shakya, 2015). Results from the survey indicated that the top four earthquake-related concerns were: 1) a lack of adequate housing (Figure 9-4), 2) lack of sufficient food, 3) disruptions in children's education, and 4) disruptions in farming. Housing was the number one rated concern in all affected districts by a large margin (e.g. approximately 95 percent rated housing as the major concern, while approximately 65 percent indicated food was a concern).

Figure 9-4. Destroyed home, Bhimdunga, just outside of Kathmandu (photo: Courtney Welton-Mitchell).

During interviews, we asked community members about preferred means of coping with post-earthquake stressors. As indicated previously, many community members are engaging in spiritual activities such as puja, and appear to be deriving comfort from such practice (Figures 9-5 and 9-6). We also noticed some community members using reframing, or focusing on the positive aspects of the disaster instead of what was lost. For example, in one community we visited where nearly all homes were destroyed, most of the community members we spoke with explained to us that they are happy to be alive and are focused on feelings of gratitude rather than feelings of hopelessness or distress. They went on to explain that when the earthquake occurred all adults were working in the fields, and the children were together watching a movie in one building that did not collapse (although the roof slid off). There were no deaths. So, despite the destruction of most of their homes, people said they felt thankful to have been spared, "If the earthquake came at night no one would have escaped." This type of reframing has been associated with resilience and wellbeing (Lambert et al., 2009) and may serve some communities well during the long rebuilding process ahead.

Figure 9-5. Temple in Ramkot, just outside of Kathmandu (photo: Courtney Welton-Mitchell).

Figure 9-6. Private shrine in Ramkot, just outside of Kathmandu (photo: Courtney Welton-Mitchell).

9.4 SOCIAL SUPPORT/COHESION AND CONFLICT

Mental health research has repeatedly emphasized the value of social support in aiding recovery. While disasters have the potential to bring communities together, stressful events can also increase conflict, including competition over scarce resources. We asked community members if people were supporting one another in the aftermath of the earthquake—whether neighbors were helping one another and to what extent conflicts had arisen. There were countless stories of volunteerism and cooperation in communities—among neighbors, and coming from local business leaders, local religious groups, and youth groups (Figure 9-7). Much has been written about this, including a piece in the New York Times on the 'new volunteerism' emerging in Nepal in the aftermath of this earthquake (Glencorse, 2015). As we travelled, we encountered several striking examples of this, most notably in a landless 'squatters' community in Kathmandu along the banks of the Bagmati River. In a community with very little in the way of basic needs, a significant sum of money had been collected to support earthquake victims in neighboring areas of Kathmandu (Figure 9-8). This same community also provided temporary shelter for dozens of families in the immediate aftermath of the April 25, 2015 earthquake when they discovered displaced former homeowners sleeping on a nearby bridge.

Figure 9-7. Community members helping to clear debris from a neighbor's home. The materials were donated by the government and humanitarian agencies, but the labor was uncompensated (photo: Courtney Welton-Mitchell).

Figure 9-8. Pre-earthquake squatter settlement along the banks of the Bagmati River, Kathmandu. Despite having very little themselves, this community raised money for earthquake victims and provided shelter for those homeless as a result of the earthquake (photo: Courtney Welton-Mitchell).

Although the spirit of cooperation and volunteerism we observed was impressive, we also heard stories of conflict in communities, including conflicts between neighbors related to perceptions of caste/ethnic discrmination (see Section 9.8 for more details). Additional community conflicts were reported by several interviewees and seemed to center around: 1) jealously regarding relief aid distribution practices and concerns about fairness in selection of aid recipients, 2) water use/access and similar resource issues, and 3) use of farming land for temporary settlements when it was needed for harvesting and planting. As one respondent indicated, "When there [are] relief materials, some households get jealous and fight with each other." Another person, an older man who had lost his home, told us that he expects "the community will be fighting a lot about rebuilding issues." Others indicated that mental health issues may be fueling disputes: "After what happened, many people get angry easily and are very afraid, and because of this they behave badly with each other…." Finally, some community members explained that "people seem to be less caring about each other now [after the earthquake] because they are preoccupied with their own needs."

Conflict appeared to be reported more often in urban and semi-urban places, and among mixed ethnicity/caste groups, while more ethnically homogenous rural communities appeared to be somewhat more cohesive. Socio-economic status, influencing access to resources, may also play a role in cohesion and conflict. It is important to note, however, that our interviews consisted of a convenience sample, in relatively accessible areas, in only five districts. As such, generalizations should be avoided. Let us instead consider the notion that caste/ethnicity, socioeconomic status, and geographic location are factors related to social cohesion and conflict in earthquake-affected districts in Nepal, a working hypothesis in need of more rigorous research.

9.5 REMITTANCES, REMUNERATION, AND LIVELIHOODS

We wanted to include some exploration of livelihoods (i.e. ways of earning money, or other resources such as food), and other economic issues in our community interviews, especially given the potential importance of this topic both for mental health and well-being and economic recovery in the aftermath of the earthquake. The following section includes information gathered during interviews and pulled from several credible publicly available reports.

Nepal is highly dependent on money sent home (known as remittances) from Nepalis working outside of the country. In the year before the earthquake, remittances made up 29 percent of the country's gross domestic product as shown in Figure 9-9 (World Bank, 2014b, Richter, 2014). A 35 percent increase in remittances was reported in the first few months after the earthquake (Nepal Earthquake Assessment Unit, 2015). Even before the earthquake, Nepal has been far more dependent economically on remittances than neighboring India, although India receives the largest monetary amount in remittances (4 percent of GDP for India vs. 29 percent for Nepal). "In Nepal, the outflow of migrant workers rose 16 percent in fiscal 2013-14 compared with a year earlier, supporting robust growth in remittances that have been expanding at double-digit rates since 2010" (World Bank, 2014b). The main drivers of remittances globally are: 1) number of citizens out of the country, and 2) economic conditions in the country of origin (such as Nepal's high rate of unemployment). However, natural disasters are another important factor typically leading to an increase in remittances; Indonesia after the 2004 tsunami, and the Philippines after typhoon Haiyan in 2013, are examples of this 'natural disaster effect' on remittance levels.

Figure 9-9. Nepal is third globally in terms of dependence on remittances as percentage of GDP (adapted from World Bank, 2014b by Richter, 2014).

Given the dependence on remittances in Nepal and the need to rebuild following the earthquake, it is likely that increasing numbers of young men will be leaving rural areas seeking wage-earning opportunities. We are already seeing an increase in 1) internal migration from villages to urban centers, and 2) external migration to India, Qatar, Saudi Arabia, United Arab Emirates, and Malaysia (Deshingkar, 2015). In speaking with community members, many mentioned the need for more young men to go abroad to earn income for rebuilding, while at the same time wondering how elderly people left behind will manage on their own. Ultimately this means that the "…burden of rebuilding will be placed upon women, adolescents, the sick, and the elderly because many healthy, young adult and middle-age men are not in rural communities" (IASC, 2015) as shown in Figure 9-10. Organizations such as Oxfam have recognized this and in response are targeting women for training in construction skills (Oxfam America, 2015). However, support for the elderly who are left behind will likely continue to be lacking and will need to be addressed.

Figure 9-10. Women are being left behind to spearhead rebuilding efforts as young men migrate in search of wage-earning opportunities (photo: Courtney Welton-Mitchell).

Although most Nepalis in the hardest hit areas did not have home insurance, the government announced a compensation/remuneration package just weeks after the earthquake for those who lost loved ones and property (Arko Network, 2015). Many of the community members we spoke with, however, did not feel optimistic about being able to access these funds. A typical response was “I heard the government will give NPR 15,000 for destroyed homes, but I doubt this will happen.” Several people stated that they don’t have the proper papers (identity documents and blueprints of their home) that would enable them to access funds. In some cases these documents were buried in the rubble. Several people explained that they do not have enough ‘political influence’ to claim their remuneration. This is consistent with information in news reports a few months after the earthquake indicating “When it comes to reconstruction, while Nepal's government has promised several types of benefits for victims of the earthquake, including initial grants of $144, to be followed by grants of $1,922, and loans at 2 percent interest rates for rebuilding homes, confusion is rife over how to go about obtaining them” (Rousselot, 2015). In addition to confusion and cynicism over access to compensation, community members explained that the amount of compensation for a destroyed home was about 25 percent of what it will actually cost to rebuild the same basic structure. This does not include the considerable amount of money required to demolish condemned structures and clear rubble. Many people explained that it took them 10-15 years, or longer, to build their homes, working on one room or story at a time, as money became available. Some took out loans, and as one woman in a Tamang village in Sindupalchowk district mentioned, “Everything I worked for my whole life was destroyed in a few seconds. I took out loans that I won’t be able to repay.” Given this, they explained that they don’t expect to be able to rebuild quickly. Several people we spoke with also mentioned that families renting homes, with no eligibility for compensation of lost property and nowhere to go, are facing even greater difficulties than homeowners.

Several community members expressed concerns that the earthquake will result in widespread and potentially long-lasting disruptions to the economy. Community members highlighted concerns over loss of livestock, late harvest/planting this year and potentially lower crop yields, and a decrease in tourism (Figure 9-11). One woman with two young children explained “Myself and my son were buried in our house. We dug ourselves out, but our goat, buffalo, and 46 chickens were lost. How will we recover?” We also heard concerns about a lack of available goods for small shop owners to keep up with supply demand. Despite these challenges, the earthquake—and subsequent humanitarian response—has created opportunities for some, including an increase in relief and recovery jobs for locals with humanitarian agencies and work for many ‘unskilled’ day laborers clearing the rubble and assisting in rebuilding (Figure 9-12).

Figure 9-11. The harvest and planting calendar has been affected by the earthquake (photo: Courtney Welton-Mitchell).

Figure 9-12. Many are benefitting from employment opportunities associated with rebuilding (photo: Courtney Welton-Mitchell).

9.6 RELIEF AID MECHANISMS

In order to better understand how humanitarian agencies and the government of Nepal are responding to the immediate needs of earthquake survivors, we have included a section here on relief aid mechanisms. The inter-agency 'cluster system' is the foundation of the current humanitarian response system, and may be activated in the aftermath of a natural disaster that overwhelms a local government's capacity to cope, such as with the earthquake in Nepal. The cluster system was set by United Nations General Assembly Resolution 46/182. "Clusters create partnerships between international humanitarian actors, national and local authorities, and civil society" (UNOCHA, 2015). The current cluster system is grouped into 11 sectors (e.g. health, education, logistics as shown in Figure 9-13), and has been in place since 2005 when it was first utilized following the earthquake in Pakistan that same year. Since its introduction, there have been two global evaluations of the cluster system, and the general consensus is that it has been an effective tool in streamlining and coordinating humanitarian response to natural disasters and other crises (Humanitarian Response, 2005). In Nepal there was substantial humanitarian infrastructure in place before the earthquake. As a result, the cluster system was activated quickly and appears to have functioned well.

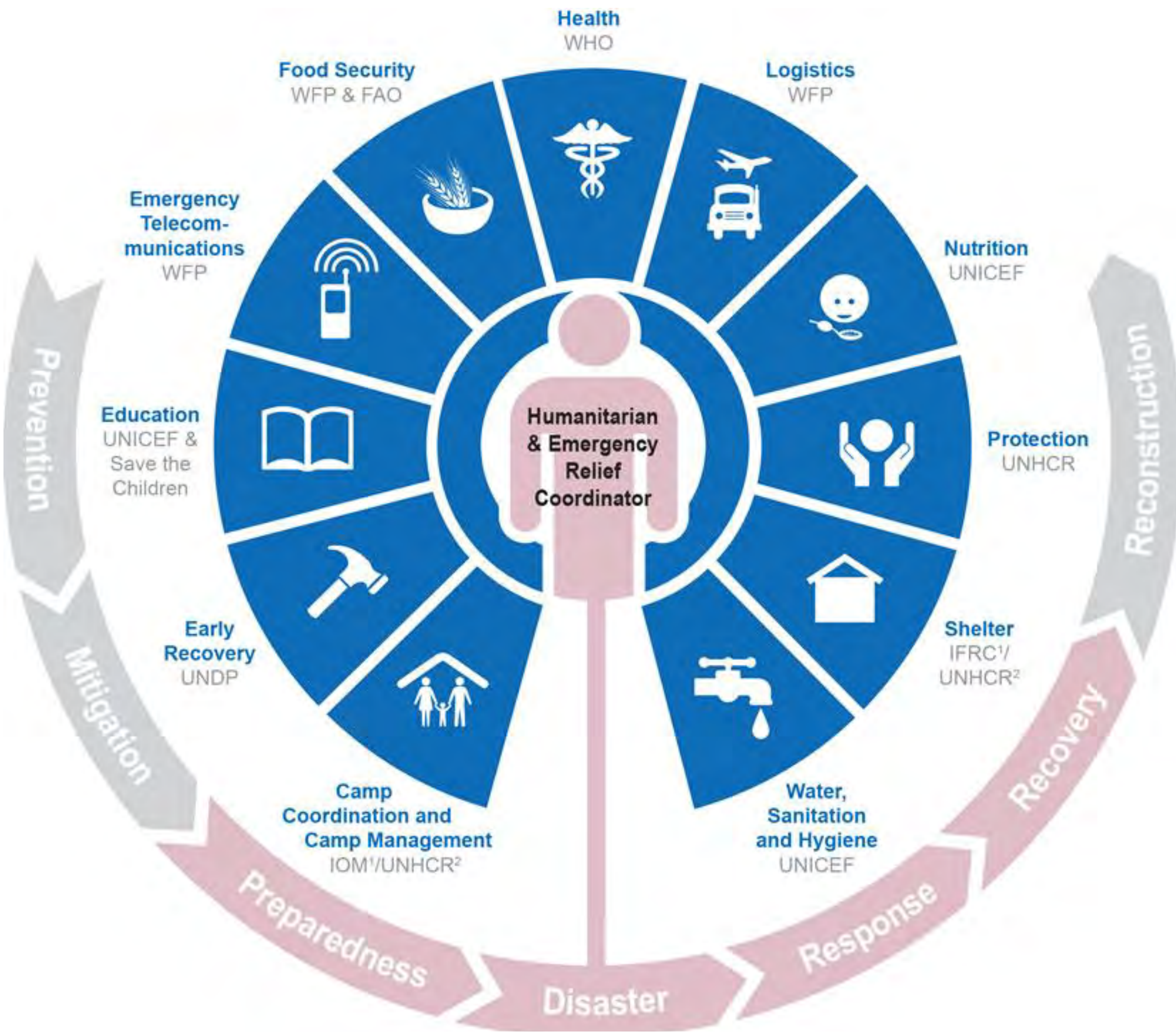


Figure 9-13. Humanitarian Cluster System (source: UNOCHA, 2015).

In the early aftermath of the earthquake, the shelter cluster was primarily involved in acquiring and distributing shelter materials including tents, tool kits, tarpaulins, and blankets. The shelter cluster is also involved in long-term rebuilding efforts. Shortly after the earthquake, the Government of Nepal completed a Post Disaster Needs Assessment (NPC, 2015) outlining long term housing recovery plans. The Shelter Cluster is supporting these plans with 30 partner agencies with disaster and reconstruction expertise (Global Shelter Cluster, 2015).

In addition to the emphasis on rebuilding in the Post Disaster Needs Assessment, within a few months of the earthquake, Nepal set up a new state body to lead reconstruction efforts, known as the National Reconstruction Authority (NRA). The government indicated that USD 6.7 billion will be required for rebuilding and that all funds should be channeled through this new body. The NRA is expected to complete reconstruction work within five years and has pledged to provide progress reports on activities every four months (China Post, 2015). The United Nations Development Programme (UNDP) is assisting the NRA for the first two years of set up and implementation. Details about this support can be found in the publicly available program brief, *Supporting Nepal in Building Back Better: National Reconstruction Planning and Implementation* (UNDP, 2015).

The topography of Nepal will continue to present major challenges for recovery and rebuilding. Many villages within the most affected districts are remote and lack adequate infrastructure for transport of materials. This was the case even before the earthquake, but the earthquake also damaged many trails and the limited road networks. Monsoon rains (June-August) also worsened some of the trails, increasing risk of landslides. The United Nations World Food Program (WFP), along with other agencies, has been relying largely on the use of helicopters and a porter and donkey network to access remote areas. WFP has also had some success in utilizing porters for repair of trails (WFP, 2015).

It is essential to get adequate trail and road networks in place; funds are insufficient for WFP to continue deliveries of food and other aid using helicopters for much longer (Nestler, 2015).

9.7 SOCIO-POLITICAL CONSIDERATIONS – GOVERNANCE, CIVIL WAR, AND CORRUPTION

During the period 1996-2006, Nepal experienced a civil war between government forces and the Communist Party of Nepal (Maoist). The civil war resulted in 15,000 deaths – mostly civilians – and an estimated 150,000 displaced persons. The Maoists are now members of the current government, known as the Federal Democratic Republic of Nepal. The 2013 elections marked an important step toward the formation of an inclusive and democratic state (World Bank, 2014a).

The country's political transition, including drafting of a new constitution, took much longer than expected. Between 2006-2015, there was no formal constitution. A few months after the earthquake, however, a draft of a new constitution was put together and passed on September 16, 2015 (Iyengar, 2015). Although seen by many as significant progress, numerous stakeholders have expressed concerns that this was pushed through without proper consultations, in order to avoid 'loss of face' in the eyes of the international community after the earthquake (Adkin, 2015). "Critics say the political elite have taken advantage of the disaster to include regressive provisions that will curb the rights of women and marginalized groups, including Dalits (Khalid, 2015)." During our interviews, numerous community members expressed cynicism about the government's ability to handle the earthquake response and rebuilding process, citing the government's inability to put a new constitution in place for the past nine years. When asked about the draft of the new constitution circulating shortly after the earthquake, some interviewees expressed concerns that the new constitution would not represent all. For information on the protests that have erupted in Southern Nepal in response to the new constitution, see the October 2015 report from Human Rights Watch, "Like We Are Not Nepali" Protest and Crackdown in the Terai Region of Nepal (Human Rights Watch, 2015). In addition, more information on the Indian blockage of Southern border that has resulted in a crisis of fuel and other essentials in Nepal has been posted in the Himalayan Times article, *Nepal's humanitarian response: Best amongst worst options* (Acharya, 2015).

Opinion polls within weeks of the earthquake indicated widespread disillusionment among the public with the government. "This year, an inadequate political response to the earthquake, the delays in the constitution and persistent political infighting seem to have heighted public disenchantment" stated the Himalmedia Nationwide Public Opinion Survey, with 3,500 respondents in 35 districts, and data collected in July 2015 (Shakya, 2015). When asked about the 'top three pressing problems facing the country' post-earthquake, survey respondents indicated: 1) inflation (64%), 2) unemployment (42%), and 3) corruption (36%).

Corruption in the public sector has long been a problem in Nepal. In 2014, Nepal slipped on the corruption perception index (Transparency International, 2014) "…earning a dubious distinction as one of the most corrupt states in the world" (Sharma, 2014). Nepal's corruption perception score for 2014 is 29/100 (with 100 being the least corrupt), and the country's rank is 126 out of 175 countries (with 175 being the most corrupt). Thirty-two percent of citizens surveyed reported having paid a bribe in the last 12 months. Sadly, these results are not surprising, in that they are consistent with what we heard during interviews. Several community members explained that they would need to pay bribes or have political connections in order to access earthquake-related remuneration or even locally distributed relief aid. In addition, many community members explained that they trusted humanitarian aid organizations to distribute aid in a fair manner, but did not trust local politicians to do the same. Several community members indicated that local politicians are keeping everything for themselves and their networks of political supporters, and using the earthquake to further their own political agenda.

While this may sound surprising, bias in the distribution of relief aid has been reported by Amnesty International, including ethnic/caste-based discrimination. "Survivors report that in some communities the aid effort has been politically manipulated," said Amnesty International's Asia-Pacific director Richard Bennett in a statement. "Those with muscle—political connections—end up claiming desperately needed supplies meant for everyone" (Moftah, 2015). For more about caste, ethnicity, and earthquake response refer to the Nepal Earthquake case Studies from Dartmouth College (2015).

9.8 GENDER, CASTE/ETHNICITY, AND LANGUAGE

Nepal is a small but culturally diverse nation, with 123 languages spoken and 102 ethnic/caste groups (Figure 9-14). Over 80 percent of the country identifies as Hindu, with a sizeable Buddhist population (Central Bureau of Statistics, 2012). The earthquake disproportionately hit specific ethnic communities, those from lower socio-economic groups, and women.

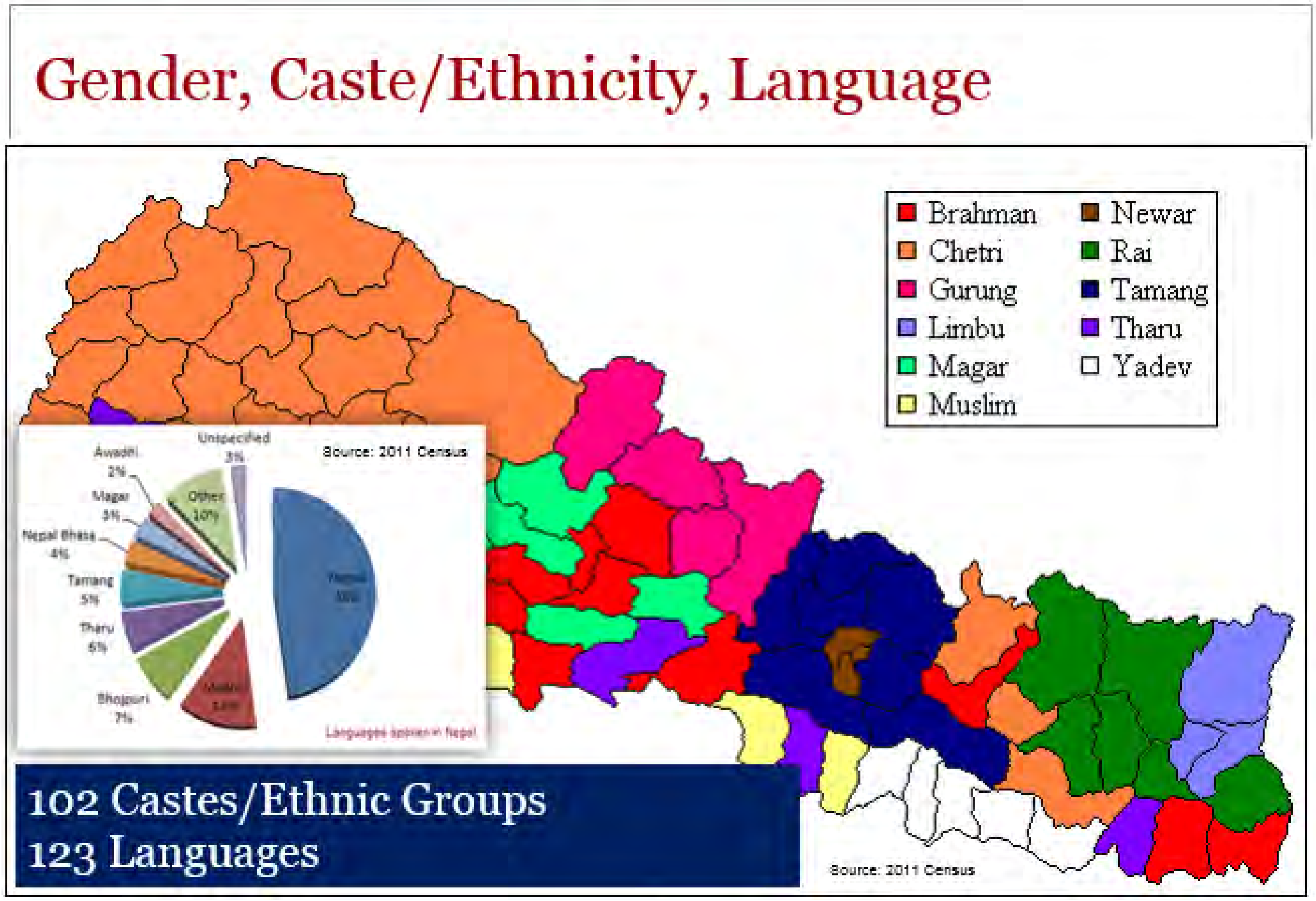


Figure 9-14. Breakdown of ethnic/caste groups by district and languages spoken in Nepal (source: Central Bureau of Statistics, 2012).

Tamang communities experienced the greatest number of casualties, followed by Brahman (Bahun) and Chhetri, and Newar. The Tamang community experienced 34 percent of earthquake-related deaths, although they are only an estimated six percent of the total population in Nepal (Figure 9-15). Tamang communities have traditionally been marginalized and oppressed in Nepalese society. As the author of an op-ed in the Kathmandu Post pointed out recently, “As we enter the phase of recovery from a disaster that has devastated the lives of thousands of Tamangs, we have been provided with a golden opportunity to finally right all these years of discrimination (Thapa, 2015).”

Ethnicity and caste are often conflated with socioeconomic status in Nepal, although they are certainly distinct constructs. The rural poor in Nepal have been hardest hit by the quake, in part due to economic and ethnic differences in use of building materials. Homes that use stone, bricks, or mud-bricks with wooden frames appeared to be more vulnerable during the earthquake than homes constructed with materials such as concrete and steel (Dixit, 2015, Sokhin 2014). In one Tamang community we visited on the outskirts of Kathmandu, nearly all residential buildings were made of brick and mud—and all but a few had been destroyed. Traditional Newari construction also includes bricks with wooden frames and ornate carved windows. This type of traditional Newari construction appears to be a contributing factor to the high death toll among Newars. They represent 14 percent of earthquake casualties, an especially high number considering that they are only six percent of the total population.

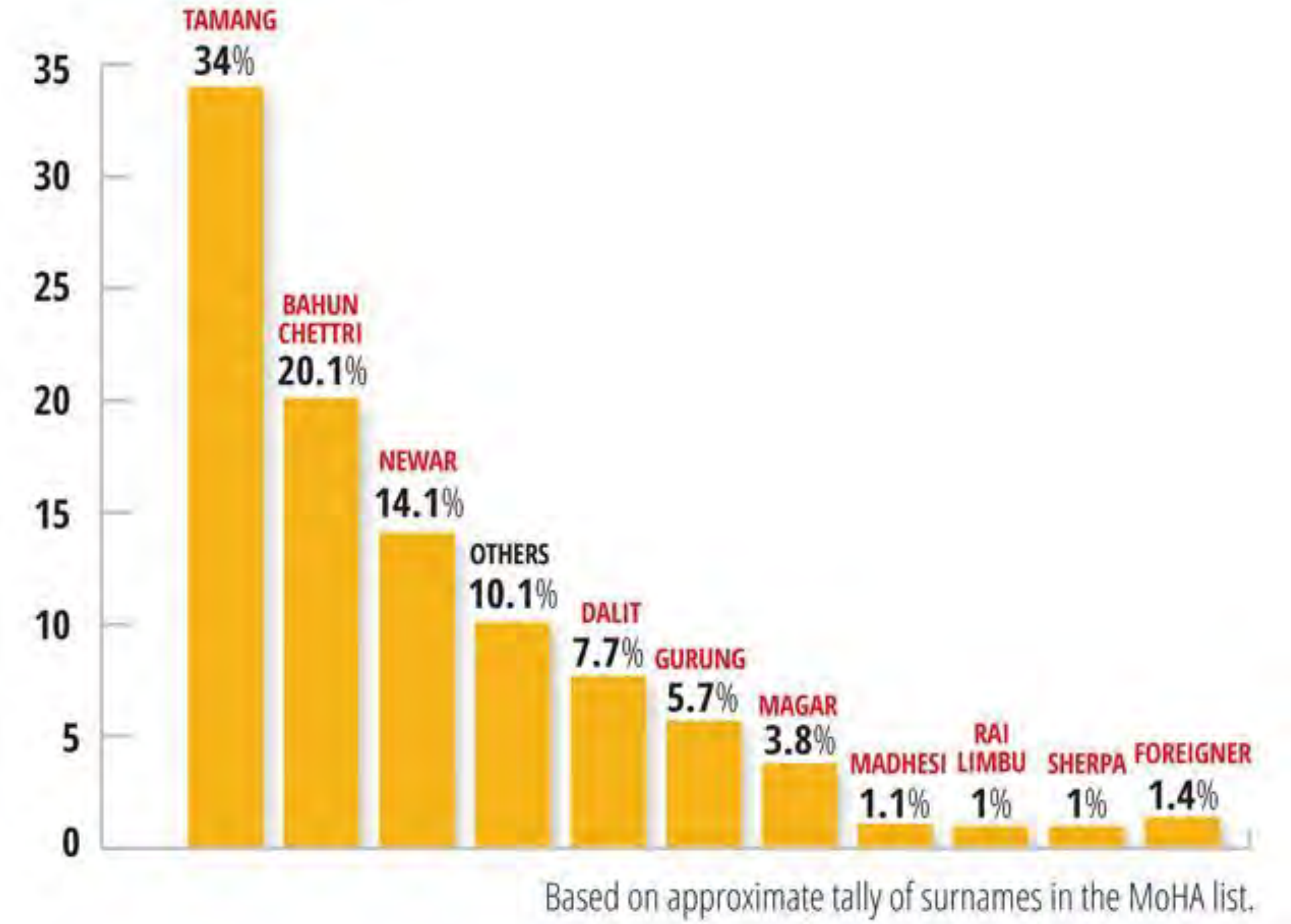


Figure 9-15. Deaths from the April 2015 earthquake in Nepal by ethnic/caste grouping (source: Magar, 2015).

Women were hit hard in the earthquake. Fifty-five percent of casualties were women (UNICGTF, 2015). Twenty-six percent of damaged houses belong to female-headed households (NPC, 2015). As highlighted in previous sections, many men have migrated out of affected areas for work, leaving women to shoulder the responsibility of rebuilding. In addition, reported increases in gender-based violence, including trafficking of women and girls, underscores the unique vulnerabilities for women and children in the aftermath of the earthquake, with separated and orphaned children at particular risk.

Child trafficking concerns were raised by stakeholders we interviewed, including officials with the Ministry of Women, Children and Social Welfare, and staff from non-governmental organizations such as Voices of Children. There is a significant demand for young Nepalese girls in Indian brothels. Local authorities in Nepal have increased trafficking prevention efforts in recent years, warning rural communities of the false promises used by traffickers to trick young girls and their families into agreeing to cross-border migration with strangers. However, many of the Nepalese law enforcement officers typically allocated for border patrol and anti-trafficking initiatives were reassigned for relief efforts after the earthquake, leaving an open door for traffickers (Frankovich, 2015).

9.9 SUMMARY AND SUGGESTIONS FOR FUTURE RESEARCH

This chapter has touched on a variety of social, psychological, and cultural factors that may influence preparedness, recovery, and rebuilding. We recommend future researchers explore such factors over the coming months and years in order to better understand contextual issues with implications for recovery and rebuilding post-earthquake. Temporary shelters were erected hastily in the aftermath of the earthquake in order to provide much needed shelter from the June-August monsoon rains. It remains to be seen what Nepal can achieve in the coming months as more permanent housing is put in place. As outlined in this chapter, the Nepali people are facing many post-earthquake challenges (Figure 9-16).

Figure 9-16. Couple clearing the rubble from their home (photo: Courtney Welton-Mitchell).

However, Nepal is a nation that is resilient, having overcome many seemingly insurmountable obstacles, both in terms of the recent civil war and other natural disasters. Hopefully, the coming months will provide an opportunity for the world to observe the spirit and resilience of the Nepali people as they build back better, providing an example of post-disaster recovery for the rest of the world to follow.

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CHAPTER 10

VIRTUAL CLEARINGHOUSE OPERATIONS

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Acknowledgements:
Many EERI volunteers supported the operation of EERI's virtual clearinghouse website for the 2015 Nepal earthquake. Special thanks go to John Bevington who was instrumental in ensuring that the reconnaissance team members could capture geolocated imagery, the reconnaissance team members who spent extra time documenting their photo observations, Ken Elwood and the LFE Executive Committee who provided advice, the Clearinghouse Curators who kept the website fresh and relevant, and the Virtual Team Collaborators who spent hours post-processing and importing team member images. Final thanks go to the EERI staff (Jay Berger, Sonya Hollenbeck, Stephen LaBounty, Juliane Lane, Setsu Uzume, Liz Stalnaker, and Ethan Jones) and interns (Kelsey Wittels, Karen Izumoto, Alianora Walker, and Alex Julius) helped with the response while also supporting ongoing activities that were pushed to the side in the flurry of the earthquake response.

10.1 VIRTUAL CLEARINGHOUSE OVERVIEW

Since 2009, the Earthquake Engineering Research Institute has been launching virtual clearinghouse websites after major international earthquakes to capture and document early information provided by investigators from a variety of disciplines, including members of EERI reconnaissance teams. The purpose of these virtual clearinghouses is to quickly share information coming from colleagues in the affected region and capture ephemeral data about each event (EERI, 2015f). In past earthquakes, virtual clearinghouses often were active during the initial response phase of the earthquake, but were rarely updated with information or reports about recovery in the months and years following the earthquake. In response to the earthquake in Nepal, EERI launched a virtual clearinghouse website (EERI, 2015a) and also added a new goal—the Nepal 2015 virtual clearinghouse website shall serve not only as a permanent archive of earthquake data from initial reconnaissance, but also as a permanent archive for data collected through the recovery and rebuilding stages.

The Nepal Virtual Clearinghouse prompted the establishment of two new volunteer roles (Clearinghouse Curators and Virtual Team Collaborators) leading to active engagement of 25 young professionals and graduate students. The Nepal Virtual Clearinghouse also facilitated record-breaking levels of archival photo documentation with captions and geolocations for nearly 11,000 team member observations, and supported online mapping of these data along with other public data sets. These successful new approaches will create a new benchmark for future EERI reconnaissance efforts while also providing useful data and support to teams conducting resilience and recovery studies in Nepal in coming years.

10.2 EERI RESPONSE

EERI responded rapidly to the Nepal earthquake and established a virtual clearinghouse for the event with 27 hours of the main shock. Table 10-1 outlines the major milestones of the response. More information about EERI's Learning from Earthquakes (LFE) program and leadership can be found in Chapter 1.

Table 10-1. Brief timeline of EERI response (in Pacific Daylight Time)

April 24, 11:11PM	Earthquake occurs at 2015-04-25 06:11:26 (UTC)
April 25, 12PM	Call with EERI staff, Learning from Earthquakes (LFE) Executive Committee Chair, and EERI President
April 25, 2PM	Notice about earthquake on EERI website
April 25, 3PM	Call with LFE Executive Committee - consider response & develop plan
April 26, 2AM	EERI virtual clearinghouse website live and operational (27 hours after earthquake)
April 26, 10AM	EERI staff joins first NEHRP coordination call
April 26, 5PM	First email blast to membership about EERI response plan
April 29	Email blast to members "Help Inform EERI Nepal Earthquake Reconnaissance Activities"
April 29	LFE Executive Committee Call #2—consideration of team leaders
May 7	LFE Executive Committee Call #3—consideration of team members (team leaders already confirmed)
May 11	Team Leaders Bret Lizundia and Surya Shrestha announced to EERI members via email
May 23	Team members announced to EERI members via email
May 30-31	Team arrives in Nepal
June 7-8	Team departs from Nepal
July 29	EERI Team Briefing Videos posted online and shared with the membership

The LFE Executive Committee has a four-phase reconnaissance recommendation plan which was implemented:

1. Initial field reconnaissance with EERI members and colleagues from India and Nepal.
2. Creation of an LFE multi-disciplinary team composed of regional experts and International participants sent to region in two to five weeks.

3. Follow-up team sent in four months to a year for study using the evaluation framework developed by EERI Resilience Observatory for documenting and measuring resilience.
4. Continuation of the virtual clearinghouse website as an archive of earthquake data through recovery and rebuilding.

The third stage of this plan is currently under development and will likely take place in 2016. The website continues to be updated with reports about the recovery process as they become available.

Throughout the response, EERI staff were regularly in contact with colleagues and members in Nepal as well as collaborating with nearly 30 international organizations also responding to the earthquake and conducting reconnaissance. Chapter 1 provides a list of collaborating organizations.

While most of EERI's response was effective and provided opportunities to introduce new features and roles (discussed in following sections), there is room for improvement in areas of efficiency and timeliness for future earthquake responses. Selecting team members to represent diversity of discipline and experience level while also aligning funding and coordination with other organizations was difficult and took several weeks. Determining the best time to travel, in light of continuing aftershocks, delayed the team departure. Producing the two primary team products (the webinar briefing and this report) took many months and were delayed beyond the ideal dissemination window because of the limitations of using volunteer reconnaissance team who had already spent hundreds of hours of limited volunteer time traveling to Nepal and processing data upon their return. Some of these delays and challenges will remain in future earthquakes, but EERI's LFE program continues to seek new ways to improve its timeliness and efficiency in responding to earthquakes.

10.3 ONLINE DATA MAP

Data collection was a key focus of this reconnaissance effort and the team members went to great lengths to geolocate and caption images while in the field, resulting in over 11,000 geotagged photos from the team. To make this data available to EERI members and others on the virtual clearinghouse website, volunteer Virtual Team Collaborators helped process the team member photos to assign captions, damage states, and discipline information. The photos were then aggregated into a single GIS layer that is published as a public online service.

The GIS layer of EERI team photos, along with several other data layers were compiled into the 2015-04-25 Nepal Earthquake Field Observations online data map (EERI, 2015c and 2015d). The map is hosted through FEMA's GeoPlatform that uses ArcGIS Online as its interface. This online data map houses data that can be filtered, searched, and viewed by members and follow-up research teams studying the earthquake in Nepal. Several data layers are hosted through the FEMA server, while others are linked from other public online data sources.

This reconnaissance effort for the Nepal earthquake is the first time EERI reconnaissance photos were published on the ArcGIS Online platform, which allows for improved data visualization and sets a new standard for earthquake reconnaissance data collection and archiving. Figure 10-1 shows the basic view of the online data map showing the USGS ShakeMap, the earthquake epicenter, and the locations of observations made by the EERI reconnaissance team.

The online map allows users to view and manipulate the data. Markers on the map identify locations of reconnaissance observations. Users can click on any point to view the data, including any associated pictures for that point. Figure 10-3b shows the information box that shows the data and photos associated with a point.

Data manipulation options include basic functionality such as the ability to zoom in and out of the map and toggle the visibility of layers. Figure 10-2 shows a detailed view of the online map with the map content window open on the left to demonstrate where users can toggle on and off data layers.

More sophisticated options allow users to apply filters and view the data tables for each data set. Figure 10-3a shows the filter options box where users can apply filters to the datasets on the map. Figure 10-4 shows the online map with an additional layer, Deaths and Casualties, visible. The figure also shows the data table for this layer below the map image. The data tables for all layers can be viewed directly in the map interface.

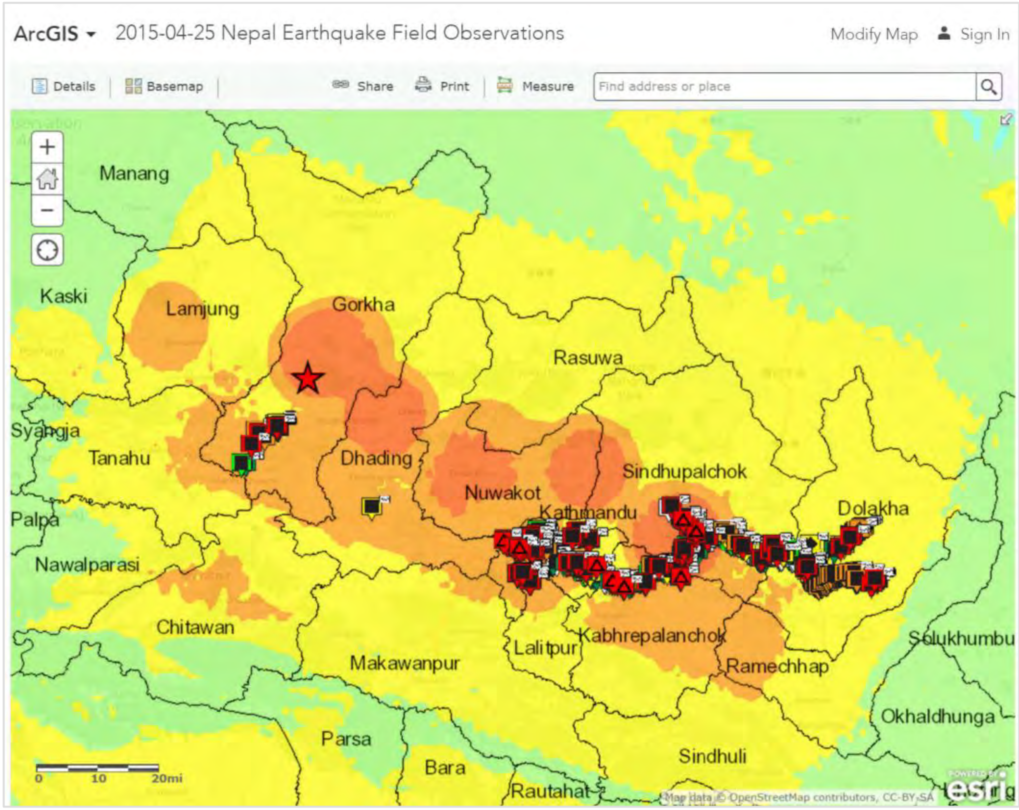


Figure 10-1. The online Nepal Earthquake Field Observations map contains over 7,000 observational data points and over 10 background data layers (EERI, 2015d, USGS, 2015, UNOCHA, 2015a and 2015b).

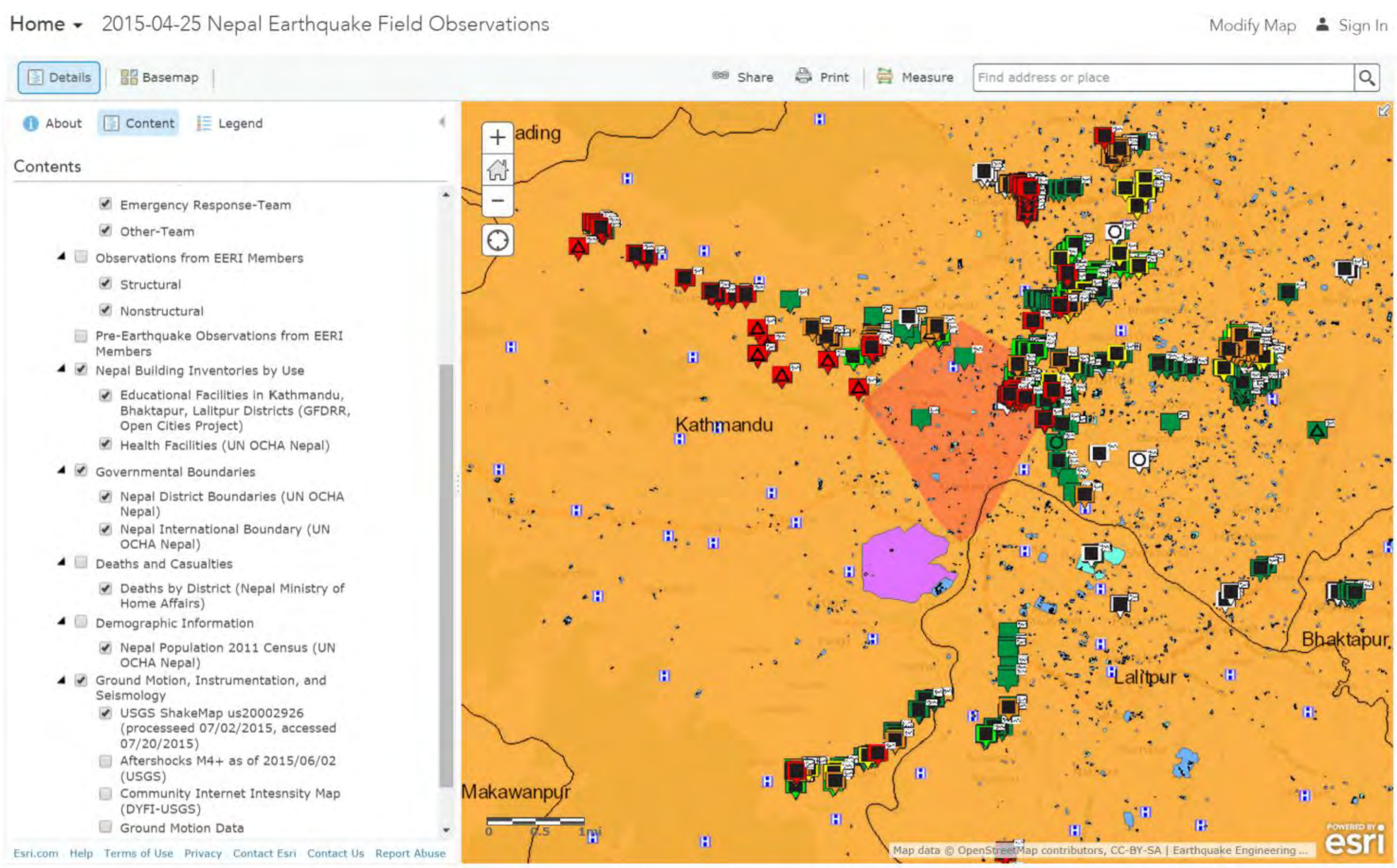
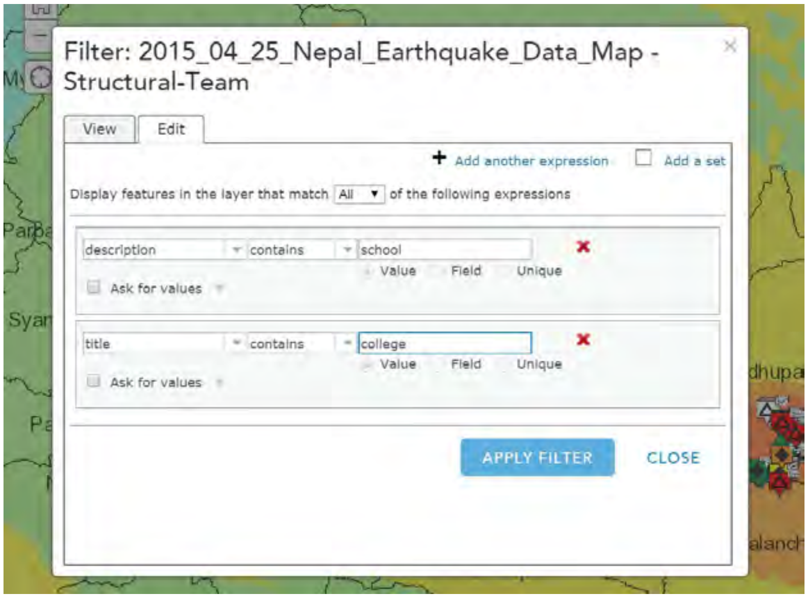
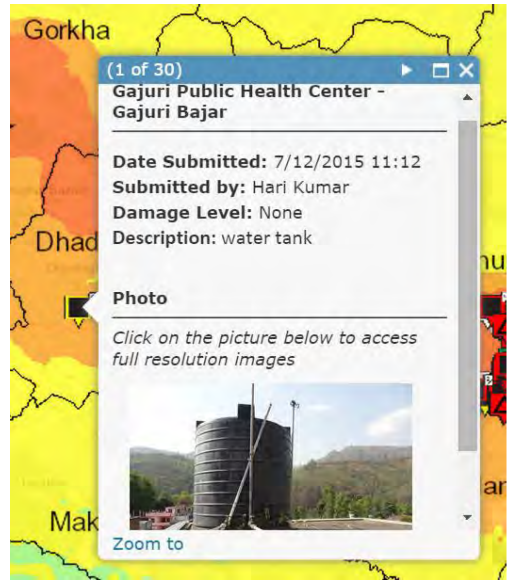


Figure 10-2. The detailed view of the map reveals the table of contents at the left, where users can toggle layers and access other data manipulation tools (EERI, 2015d, USGS, 2015, UNOCHA, 2015a and 2015b, GFDRR, 2015, WHO/SDN, 2015).



(a)



(b)

Figure 10-3. (a) Filter dialogue box showing the mechanism for filtering the datasets on the map. (b) Information box showing the details of a single observation (EERI, 2015d).

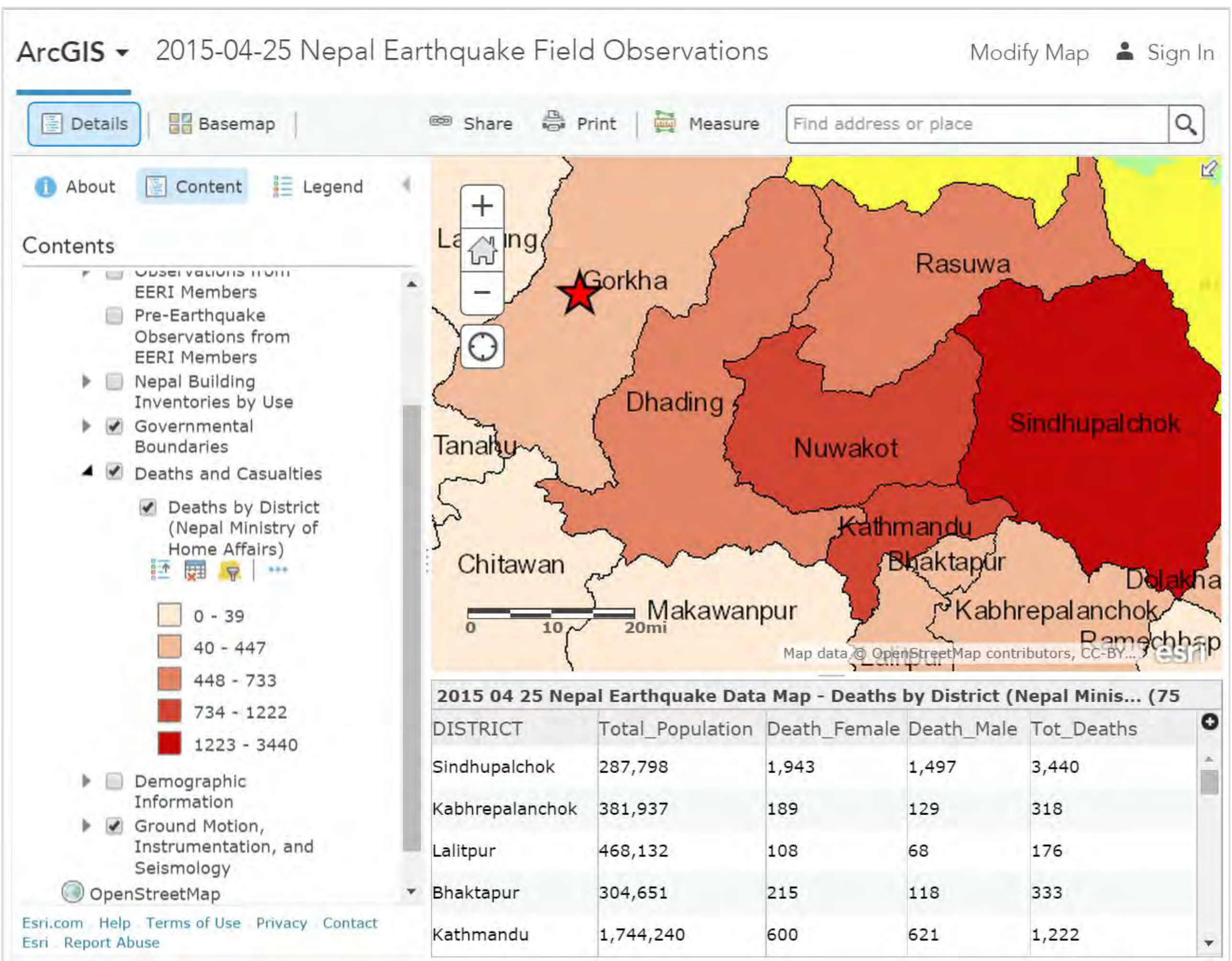


Figure 10-4. Nepal Earthquake Field Observations map showing data layer toggling abilities in the contents window on the left as well as data table view at the bottom of the map image (EERI, 2015d, USGS, 2015, UNOCHA, 2015a, NMH/NP, 2015).

While the new online data map and the team photos data set are outstanding accomplishments for EERI, there were challenges associated with developing these products.

The first challenge was that EERI's current data collection methods necessitated post-processing photos. Post-processing mainly included geolocating photos, geotagging photos, and assigning EXIF data such as photographer and copyright. Virtual Team Collaborators, described in Section 10.5, performed all of the photo post-processing, which was a significant effort and limited their ability to engage in more meaningful tasks related to the reconnaissance effort. EERI is planning to update its data collection tools and methods to in order to reduce, if not eliminate, the amount of photo post-processing necessary.

In addition to the necessary photo post-processing, once photos and data were uploaded to the online database, additional processing of the dataset was necessary before the data could be added to the ArcGIS Online map. The team photo data was manually exported from the online database, then GIS software was used to assign symbols, parse data, and check data for consistency before re-publishing the final dataset to the ArcGIS Online map. EERI plans to improve the online database structure which, along with updates to the data collection tools, will make it possible to feed the team photo data directly into the ArcGIS Online map without any need for processing.

Finally, EERI also struggled to sift through and make good use of the numerous datasets related to the earthquake that were being published online by other organizations. These datasets had the potential to inform team coordination efforts before the team departed for Nepal, but unfortunately a map of useful datasets was not developed quickly enough to be useful during the team planning stage. To address this, EERI plans to target specific types of data after future earthquakes, instead of conducting an extensive survey of available data, which should reduce the time required to aggregate data into a single map. EERI will then aim to publish the data map in time for the first team coordination call to ensure that this information is available to teams as they begin to plan their trip.

10.4 CLEARINGHOUSE CURATORS

A new volunteer role was created for this earthquake called a "Clearinghouse Curator." This role was envisaged as a way to capitalize on the interest of EERI members who are interested in the earthquake and willing to act in support of EERI's response, but located in regions remote to the earthquake. In particular, this role was designed to especially attract early career professionals and students who have both the technical skills to update website content and the knowledge about earthquake engineering and risk reduction disciplines to carefully glean and summarize useful information from media sources.

As defined for this earthquake, Clearinghouse Curators were responsible for gathering and gleaning information from media reports and technical resources for a particular topic into curated summaries that they posted on the earthquake's virtual clearinghouse website (EERI, 2015e). Their well-crafted summaries were used to help inform reconnaissance activities, identify impacted regions, help document the timeline of earthquake response/recovery, and populate the clearinghouse with relevant information. As a benefit for serving in this capacity, volunteers increased their exposure by name recognition on their posts, and made them more likely candidates for consideration on future reconnaissance efforts, and possible follow-up missions.

This role was advertised and launched about four days after the earthquake. Twenty volunteers served as curators for the ten topics shown in Table 10-2, and resulted in over 100 curated summaries posted on the website (EERI, 2015e).

The establishment of this new role successfully achieved the EERI staff goal to have more timely and interesting topical posts to the virtual clearinghouse and to prevent delays in posting from limited EERI staff availability for website updating. Additionally, preliminary feedback from the volunteers indicated that they felt the experience was interesting and valuable.

Table 10-2. Clearinghouse Curator volunteers for the 2015 Nepal Earthquake EERI Virtual Clearinghouse

Curated Topic	***Clearinghouse Curators***
Emergency Response, Social Impacts, and Community Resilience	Lauren Biscombe and Candice Avanes (Arup), and Erica Fischer (Purdue University)
Communication Technologies	Louise K. Comfort and students (University of Pittsburgh)
School Buildings	Tracy Becker (McMaster University), Laura Whitehurst (Walter P Moore), and Veronica Cedillos (Applied Technology Council)
Hospitals	Bishnu Pandey (British Columbia Institute of Technology) and Anna Weiser-Woodward (Walter P. Moore)
Housing	Sahar Derakhshan (PEER) and Ezra Jampole (Stanford University)
Design Codes and Construction Practices	Deepak R. Pant (University of Toronto)
Seismology and Aftershocks	Renate Hartog (Pacific Northwest Seismic Network)
Geotechnical Impacts: Landslides, Liquefaction, etc.	Patrick Bassal and Alex Wright (Amec Foster Wheeler), Ashly Cabas and Brett Maurer (Virginia Tech), Diane Moug (UC Davis)
Heritage/Historic Buildings	Camilla Favaretti (UC Irvine)
Dams and Hydropower	Bishal Subedi (Aurecon)

10.5 VIRTUAL TEAM COLLABORATORS

Another new role was established for this earthquake in an attempt to engage more early-career professionals and students in reconnaissance activities. Each reconnaissance field team member was paired with a Virtual Team Collaborator (VTC) in a matching discipline or interest area. The VTC responsibilities included the following items, though tasks varied depending on the needs of each field team member: (1) Pre-departure information synthesis of the most important information, reports, articles, or locations of particular interest to the team member's role and focus areas. VTCs were asked to concisely share the most relevant information, not necessarily all information due to the field team members' limited time prior to departure; (2) Dissemination support upon return of Field Team Member to help upload field images and captions to the data map or help clean up any messy field contributions. Some VTC volunteers also contributed to the compilation and review of text or slides for this report or the briefing video series described in Chapter 1 (EERI, 2015b).

Thirteen VTCs volunteered for the Nepal Earthquake, as shown in Table 10-3. EERI staff selected VTCs based on the following criteria: past EERI involvement, current EERI membership, expressed interest in participating, relevant skills or knowledge about the region impacted by the earthquake, and expertise/disciplinary match with team members.

Both the curator and VTC roles were conceived as ways to leverage the expertise and enthusiasm of EERI members while enhancing EERI's response in learning from earthquakes. Recruitment, responsibilities, and best practices of the roles are still evolving, but outcomes so far have been generally positive. By demonstrating of their interest and involvement in earthquake reconnaissance, it is envisioned that these early-career professionals and students may become stronger candidates for future reconnaissance field teams. The LFE Operations procedure and LFE website (EERI, 2015g) have been updated to include these roles, and recommend the use of these roles again in response to future earthquakes. As the VTC roles evolves over time, it is hoped that future team members can more heavily utilize the enthusiasm of VTCs so they can play a stronger and more meaningful role in team pre-departure planning and post-trip activities.

Table 10-3. Virtual Team Collaborators (VTC) volunteers for the 2015 Nepal Earthquake

VTC	***VTC Affiliation***	***VTC Title***	***Team Member***
Deepak Pant	University of Toronto	Post-Doctoral Fellow	Bret Lizundia
Chiara McKenney	Estructure, Oakland, CA	Structural Designer	Surya Narayan Shrestha
Tracy Becker	McMaster University	Assistant Professor	Hari Kumar
Martha Cuenca	University of Illinois at Urbana-Champaign	Ph.D. Student	Chris Poland
Melissa Tucker	Aurora Mental Health Center, Aurora, Colorado	Community Education Coordinator	Courtney Welton-Mitchell
Lisa Krain	Johns Hopkins University	Ph.D. Student	Judy Mitrani-Reiser
Sabina Surana	Reid Middleton, Everett, Washington	Project Engineer	Hemant Kaushik
Lisa Shrestha	University of Buffalo	Ph.D. Student	Rachel Davidson
Brett Maurer	Virginia Tech	Ph.D. Student	Jan Kupec
Diane Moug	University of California, Davis	Ph.D. Student	John Bevington
Camilla Favaretti	University of California, Irvine	Ph.D. Student	Suraj Shrestha
Jennifer Lazo	City of Berkeley, California	Emergency Services Coordinator	Ganesh Kumar Jimee

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