Geotechnical Engineering Journal of the SEAGS & AGSSEA Vol. 46 No.4 December 2015 ISSN 0046-5828

Characteristics and Consequence of Nepal Earthquake 2015: A Review

A S M Fahad Hossain[1], Tuk Lal Adhikari[2], Mehedi Ahmed Ansary[3] and Quazi Hamidul Bari[4]
[1]*Lecturer, Department of Civil Engineering, Ahsanullah University of Science and Technology*
[2]*President, Nepal Geotechnical Society and Managing Director, ITECO Nepal*
[3]*Professor, Department of Civil Engineering, Bangladesh University of Engineering and Technology*
[4]*Professor, Department of Civil Engineering, Ahsanullah University of Science and Technology*
E-mail: fahadrubel@gmail.com

ABSTRACT: An earthquake is a natural disaster that comes in different parts of the earth every year. Most of them are very weak and unnoticeable. But some of them are too severe to cause a great loss of lives and destruction of properties. A major earthquake happened in Nepal on 25th April 2015. More than 8,000 people died and more than 19,000 people got wounded in this earthquake. People of Nepal had anticipated but never experienced such a devastating earthquake. This paper deals with the Gorkha earthquake in Nepal, its causes and characteristics, previous earthquake history of Nepal, consequences etc.

KEYWORDS: Nepal, Geology, Seismicity, Earthquake, Damages, Gorkha, Reverse Fault.

1. INTRODUCTION

Nepal, officially, the Federal Democratic Republic of Nepal, is a landlocked country located in south Asia with an area of 147,181 square kilometres and a population of approximately 27 million. Nepal is the world's 93rd largest country by land mass. It is 41st most populous country in the world. It is located in the Himalayas and bordered to the north by the People's Republic of China, and to the south, east and west, by the Republic of India. Nepal is separated from Bangladesh by the narrow Indian Siliguri corridor and from Bhutan by the Indian state of Sikkim. Figure 1 shows the location map of Nepal of south Asia. Kathmandu is the capital city of Nepal and the largest metropolis. The city is the urban core of the Kathmandu valley in the Himalayas, which also contains two sister cities namely Patan or Lalitpur, 5 kilometres (3.1 mi) to its southeast and Bhaktapur, 14 kilometres (8.7 mi) to its east. Kathmandu city stands at an elevation of approximately 1400 metres (4600 ft) in the bowl-shaped valley in central Nepal surrounded by four major mountains, namely: Shivapuri, Phulchowki, Nagarjun and Chandragiri. The city has been subjected to frequent earthquakes of moderate intensities and about once in a century. to disastrous earthquake of higher magnitude. On June 7th, 1255 AD earthquake was first recorded in Nepal when one third of the total population in Kathmandu was killed by a earthquake of 7.7 Richter scale. On Saturday April 25th, an earthquake of moment magnitude 7.8 struck the Gorkha district of Nepal, and over 367 aftershocks (of ML > 4.0) have also struck the region including a ML 6.8 in the mountains causing a landslide. In 81 years since 1934, it was the biggest earthquake to strike the country. The devastating earthquake was felt across the region from India to China and left immense destruction, flattening sections of Kathmandu and triggering avalanches in Mount Everest region.

Figure 1 Map of Nepal (Asia Nepal Map)

2. GEOLOGY OF NEPAL

Geologically, Nepal and the Himalayan range that form their northern borders with China were formed as a result of the collision of the Indo-Australian plate with the Eurasian plate since 50 million years ago. This collision process still continues and makes Nepal and the entire Himalayan range. seismically one of the most active strips on the earth.

Geographically, the country may be divided into three ecological belts running east west:

- Arid and cold Tibeto-marginal belt behind the Himalayas in the north
- Mountainous region in the middle, and
- Flat and fertile lowland known as the Terai along the border with India.

Several rivers that originate in the Himalayas cut across these ecological zones that created many river valleys and some of the most rugged terrains on earth, and feed into the Ganges. Because of the malaria and thick tropical forest infested with wildlife, the Terai, till late 1950's, was a forbidden place to live. Figure 2 shows the geological map of Nepal.

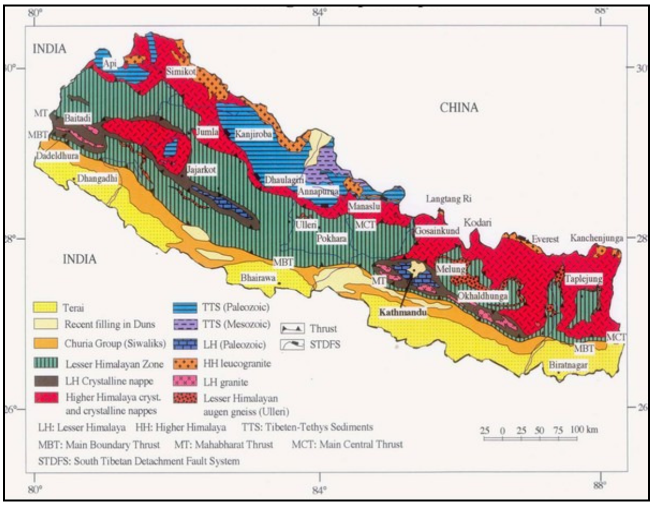

Figure 2 Geological Map of Nepal (Sajha.com)

Natural disasters are common in Nepal. The country is geologically young and still evolving. So, landslides and earthquakes are common and frequent. Because of its mountainous topography and the fact that the country comes under the spell of the monsoon every summer, flash floods, regular floods and flood- and earthquake-triggered landslides are also quite common. The increase in population and the change in its distribution also means that the country is now faced with a new set of natural disaster risks, which are:

- Earthquake (potentially lethal, liquefaction becoming a serious cause)
- Floods and flash floods (annual phenomenon but the impact is increasing due to global warming)
- Landslides induced by earthquakes, torrential rains, and natural geological change (frequent and deadlier)
- Droughts (occasional)

2.1 Seismicity of Nepal

The earthquake activity in Nepal is caused by the ongoing continental collision between Indo-Australian and Eurasian plates (Figure 3). The Himalaya Mountains and the Tibetan Plateau were created by that collision. The collision zone wraps around the northwest promontory of the Indian sub-continent in the Hindu Kush region of Tajikistan and Afghanistan then extends to the southeast through Nepal and Bhutan. The motion of India into Asia is nearly perpendicular to the Himalaya Mountains in Nepal. So that earthquakes from reverse thrust faulting are the most common kind of earthquakes in the central Himalayan region. This earthquake occurred as the result of thrust faulting (reverse faulting) between the sub ducting Indo-Australian Plate and the overriding Eurasian Plate to the north.

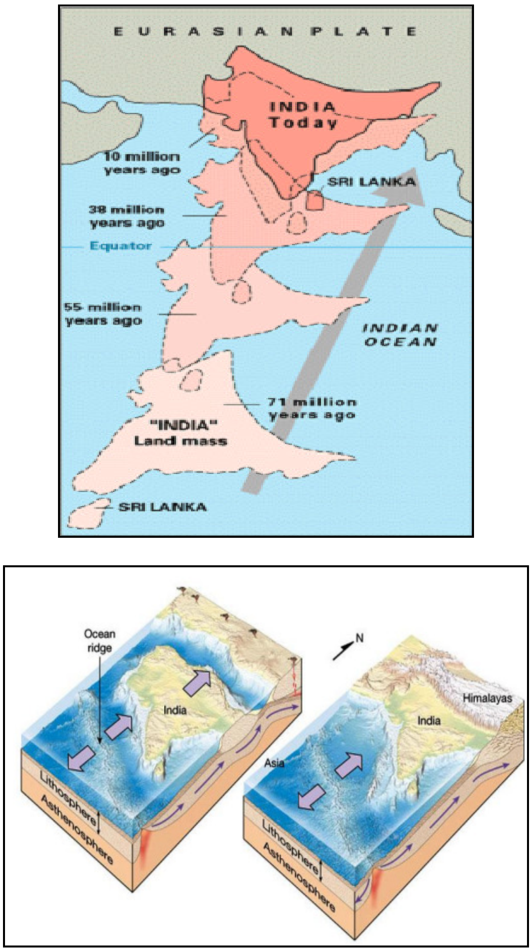

Figure 3 Collisions between Indian and Eurasian Plates
(IRIS Education & Public Outreach and The University of Portland)

Northward under thrusting of Indo-Australian plate beneath Eurasian plate generates numerous earthquakes that consequently make this area one of the most seismically hazardous on the earth. The earthquake hazard map (Figure 4) illustrates the peak ground acceleration expected to be exceeded with 10% probability during a 50-year period. The dark red zones indicate accelerations of about 0.5g where g stands for acceleration due to the gravity.

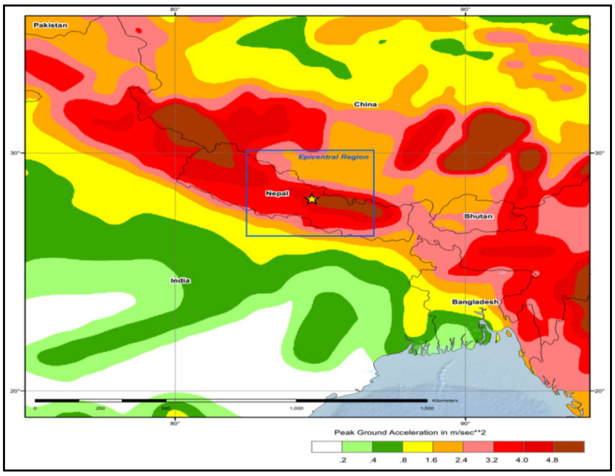

Figure 4 Earthquake Hazard Map of South Asia
(IRIS Education & Public Outreach and The University of Portland)

2.2 Past Earthquake History

Nepal and particularly Kathmandu valley are seismically vulnerable, however study of the seismic hazard potential of the valley has not been performed systematically. The map in Figure 5 shows epicenters of earthquakes since 1990 (ML > 4.0) within the collision zone. Note the belt of earthquakes along and south of the Himalaya mountains sweeping through Nepal (yellow outline). Four earthquakes with ML > 6.0 have occurred within 250 km of the April 25 Gorkha earthquake over the past century. The largest ones included a Mw 6.9 in August 1988 and a Mw 8.0 in 1934 which severely damaged Kathmandu. The 1934 earthquake is thought to have caused around 10,600 fatalities. Kathmandu city has been subjected to frequent earthquakes of moderate intensities and about once in a century to disastrous earthquake of higher magnitude. Earthquake was first recorded in Nepal on June 7th, 1255 AD. In that earthquake, one third of the total population in Kathmandu was killed by a 7.7 Richter scale. Recent earthquakes near Kathmandu city are shown in Figure 5. Table 1 shows information of some historical earthquake in and around Nepal.

2.3 2015 Gorkha Earthquake

In the noon of 25th April 2015, a magnitude of Mw 7.8 earthquake occurred with an epicenter 77 km (48 miles) northwest of Kathmandu. The quake hit at 11:56 am local time (06:11 GMT) according to US Geological Survey (USGS).

The salient features of Gorkha earthquake are as follows:

Date: 25th April 2015
Time: 11:56 AM
Epicenter: Barpak village, Gorkha district (Latitude 28.240 deg, Longitude 84.750 deg)
Strong shaking time: 40 seconds at Department of Mining and Geology
Mechanism: low angle thrust, reverse fault
Number of aftershocks: 367 (until 2nd August 2015)
Largest four aftershocks: ML 6.6 Gorkha, ML 6.9 Sindhupalchowk, ML 6.8 Dolakha and ML 6.2 Dolakha
Magnitudes: ML 7.6 (local magnitude), Mw 7.8 (moment magnitude)

Table 1 Historical Earthquake in and around Nepal (Wikipedia)

Date	Time‡	Place	Latitude	Longitude	Fatalities	Moment Magnitude
7 June 1255	-	Kathmandu	27.7	85.3	30% of population	
26 August 1833	-	Kathmandu/Bihar	28.3	85.5		8.0
7 July 1866	-	Kathmandu	27.7	85.3		6.5
28 August 1916	06:39	Nepal/Tibet	30.0	81.0		7.7
15 January 1934	08:43	Nepal/Tibet	26.773	86.762	10,600	8.0
27 June 1966	10:41	Nepal/India border	29.554	80.854	80	6.3
29 July 1980	14:58	Nepal/Pithoragarh	29.598	81.092	200	6.5
20 August 1988	23:09	Kathmandu/Bihar	26.775	86.616	1,091	6.6
18 September 2011	06:29	Sikkim	27.33	88.62		6.8
25 April 2015	11:56	Kathmandu/India/Tibet	28.147	84.708	8,456	7.8
12 May 2015	12:51	Nepal/China/India	27.97	85.96	157	7.3

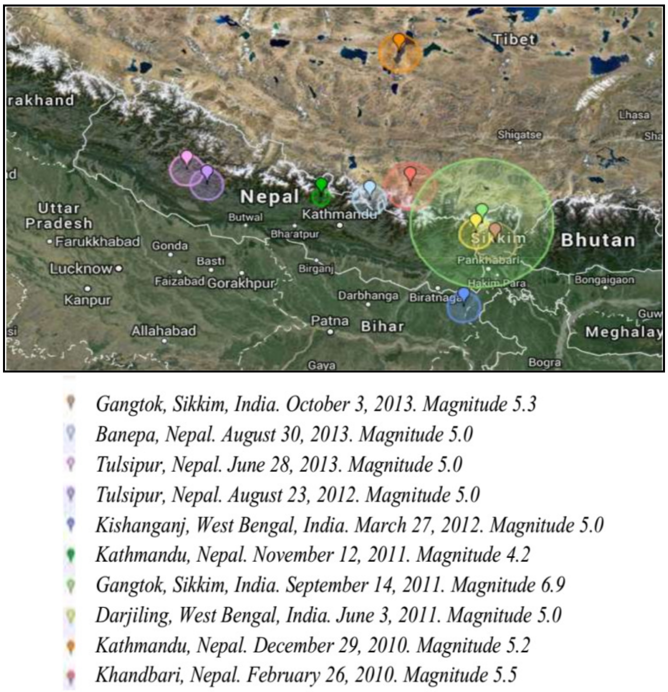

Figure 5 Recent earthquakes near Kathmandu city (Samyog Shrestha)

The earthquake flattened homes, buildings and temples, causing widespread damage across the region and killing more than 8000 and injuring more than 19,000 people. The earthquake centered outside Kathmandu, the capital, was the worst to hit Nepal in over 81 years. Fourteen districts severely-affected by the earthquake are Gorkha, Kathmandu, Bhaktapur, Lalitpur, Sindhupalchowk, Sindhuli, Ramechhap, Dolakha, Nuwakot, Dhading, Rasuwa Solukhumbu, Okhaldhunga and Kavre Palanchok districts. An additional 14 districts have reported medium level damages. Many buildings in Kathmandu valley have collapsed, including historical landmarks such as UNESCO World Heritage temples at Basantapur Durbar Square and the historic nine storey Dharahara tower in Kathmandu by the disaster. Mount Everest base camp 1 and Mount Everest base camp 2 were severely damaged as a result of avalanches in the Himalayas. In the Langtang valley located in Langtang National Park around 250 people were reported missing after an avalanche hit the village of Ghodatabel and the village of Langtang. The avalanche was estimated to have been two to three kilometres wide. It was announced that 52 bodies had been found in the Langtang area, of which seven were of foreigners on 4th May. The intensity map of this earthquake of Nepal and its neighbor countries are shown below in Figure 6 and Figure 8.

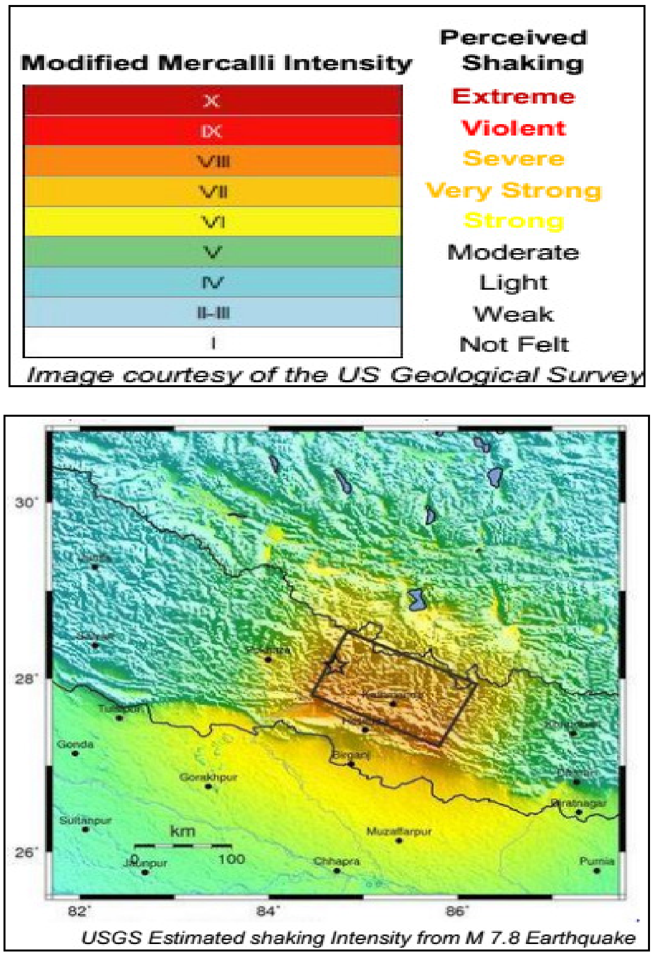

Figure 6 The Modified Mercalli Intensity (MMI) scale depicts shaking severity. The area nearest Katmandu experienced very strong to severe shaking. (www.slideshare.net)

On 26th April 2015, a major aftershock of magnitude 6.7 M_w occurred in the same region at 12:55 NST (07:09 UTC), with an epicenter located about 17 km (11 mi) south of Kodari, Nepal. The aftershock caused fresh avalanches on Mount Everest and was felt in many places in northern India including Kolkata, Siliguri, Jalpaiguri and Assam. The aftershock caused a landslide on the Koshi Highway which blocked the section of the road between Bhedetar and Mulghat. This map shows the magnitude Mw 7.8 earthquake (main shock) and the distribution of 40 aftershocks of magnitude 4 or larger that occurred over the following 27 hours. The aftershock distribution outlines the rupture zone of the main shock. The rupture during the main shock initiated beneath the epicenter and propagated toward the southeast.

Aftershock sequences follow predictable patterns as a group, although the individual earthquakes are themselves not predictable. The graph shows in Figure 8 how the number of aftershocks and the magnitude of aftershocks decay with increasing time since the main shock. The number of aftershocks also decreases with distance from the main shock.

The peak ground accelerations recorded at Kantipath, Kathmandu by USGS KATNP station is presented in Figure 7. The corresponding spectral acceleration shows interesting feature of peaking between 3 to 7 seconds.

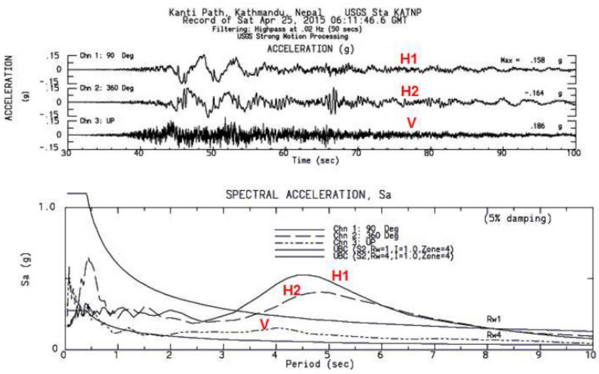

Figure 7 Peak Ground Acceleration and Corresponding Spectral Acceleration of Main Shock of Gorkha Earthquake (USGS KATNP)

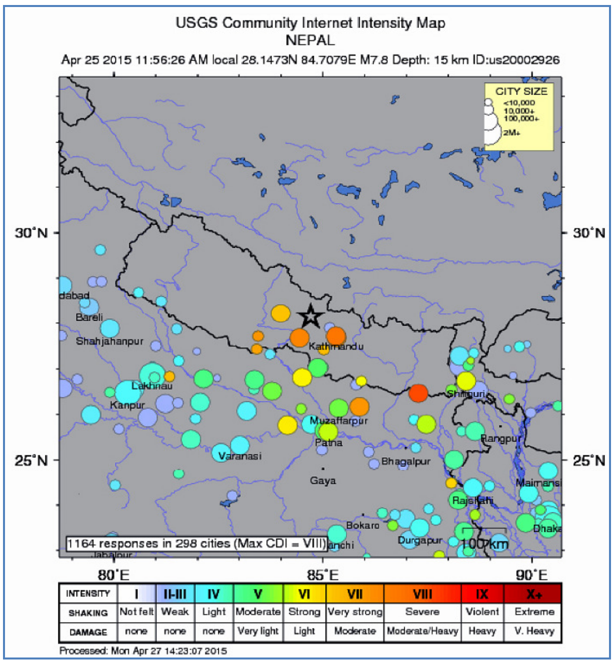

Figure 8 USGS Community Internal Intensity Map (U.S. Department of the Interior U.S. Geological Survey)

On 12th May 2015, a second major earthquake occurred at 12:51 NST with a moment magnitude (M_w) of 7.3 M_w 18 km (11 mi) southeast of Kodari. The epicenter was at Sunkhani of Dolakha district near the Chinese border between the capital of Kathmandu and Mt. Everest. It struck at the depth of 18.5 km (11.5 miles). This earthquake occurred along the fault close to the original magnitude Mw 7.8 earthquake of 25th April. As such, it was considered to be an aftershock of the 25th April quake. Tremors were also felt in northern parts of India including Bihar, Uttar Pradesh, West Bengal and other North-Indian States. As a result of the aftershock at least 117 died in Nepal and about 2,500 were injured. Seventeen others died in India and one in China. Figure 9 shows the intensity distribution of 12th May earthquake.

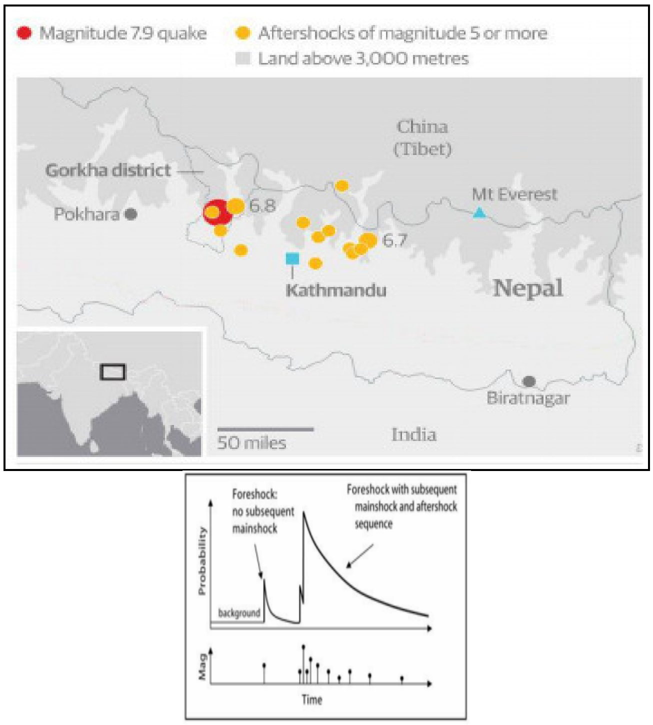

Figure 9 Locations of main shock and aftershock in Nepal (US Geological Survey)

2.4 Aftershocks Trends

A total of 367 shocks including main shock of local magnitude greater than 4.0 in Richter scale were recorded and published during first 100 days of the main shock by National Seismological Center, Department of Mines and Geology, Kathmandu, Nepal. Figure 11 depicts the trend of aftershocks starting from the main shock of ML 7.6 of Gorkha earthquake. The chart shows that the magnitude of aftershocks reduces gradually

The epicentres of all the aftershocks of Gorkha earthquake were densly distributed within geographical region of 84.6°E to 86.5°E and 27.4°N to 28.4° as depicted in Figure 12. Though the epicentre of the main shock was at the western end of the ruptured zone, all subsequent epicentres were recorded towards east of Barpak and most damages had occurred in Sindhupalchowk district which is midway of the epicentre zone. This indicates that Gorkha earthquake showed strong directivity.

The hypocenters of the series of Gorkha earthquake are presented in Figure 13 in the geological cross secton of Nepal Himalayas. It is noted that the locations of foci are all located in the sub horizontal fault surface of the Main Himalayan Thrust.

According to three moment tensor solution reported by USGS, scalar seismic moment of Gorkha earthquake is very well constrained within 5.44 to 7.76x10^{20} Nm corresponding to Mw 7.8 to 7.9. The centroid depth estimates range from 10 to 24 km and the mechanism shows a low angle NNE dipping fault plane with strike of 290 to 295 degrees, dip of 7 to 11 deg and raking angle of 101 to 108 degrees. More details on the features of Gorkha earthquake are presented in recently published GEER Report No. 040, 29th July 2015.

Another interesting feature of Gorkha earthquake and its sequence of aftershocks was that most of the strong quakes above ML 6.0 had occurred within two hours after midday as shown in Figure 14. Similar trend was observed in Great Japan earthquake earlier. More researches are to be made to explain the reason for this behavior.

Another observation on number of aftershocks during next 24 hours experienced in Gorkha earthquake is shown in Figure 15. If a significant aftershock (largest during the last 24 hours) is encountered, the number of aftershocks of smaller magnitude during the next 24 hours can be very well estimated using this figure with 89% correlation. This predictive model was found highly useful for the public information during three months of Gorkha earthquake.

The seismic energy released by Gorkha earthquake was plotted with dates during the first 100 days of the main shock as shown in Figure 16. The trend of of seismic energy release in logarithmic scale (y-axis) is quite similar to that of magnitude of aftershocks shown in Figure 10. The total moment of the earthquake was howver in the range of 3×10^{20} Joules as reported by USGS.

All the shocks of Gorkha earthquake were shallow with hypocentral depths between 5 km and 30 km as per published data from the USGS as plotte in Figure 17. This is understood as one of the major cause for larger scale damages to ground and structures seriously in 14 districts and less severely in another 14 districts.

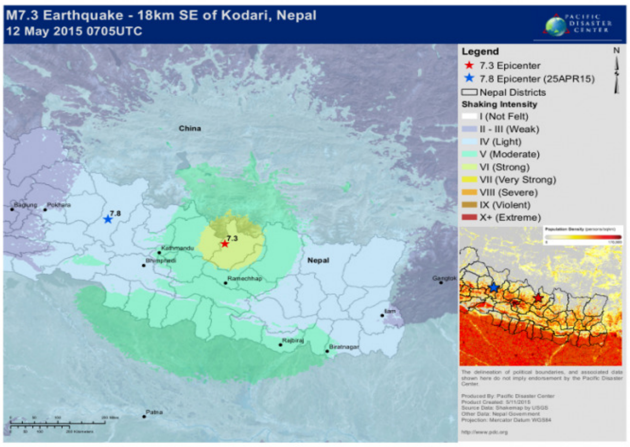

Figure 10 Intensity Distribution of 12th May Earthquake in Nepal (Pacific Disaster Center)

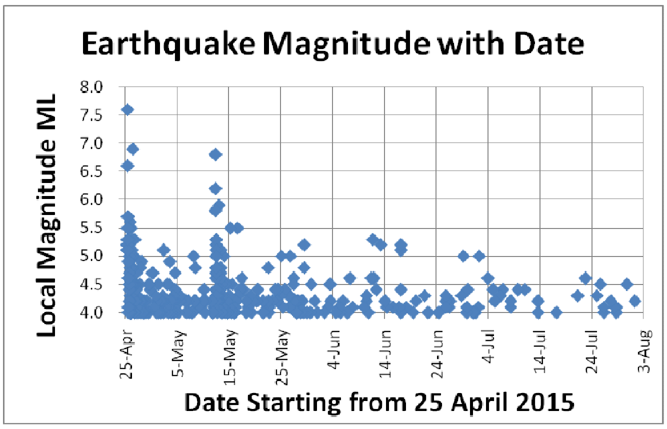

Figure 11 Aftershocks Magnitude of Gorkha Earthquake

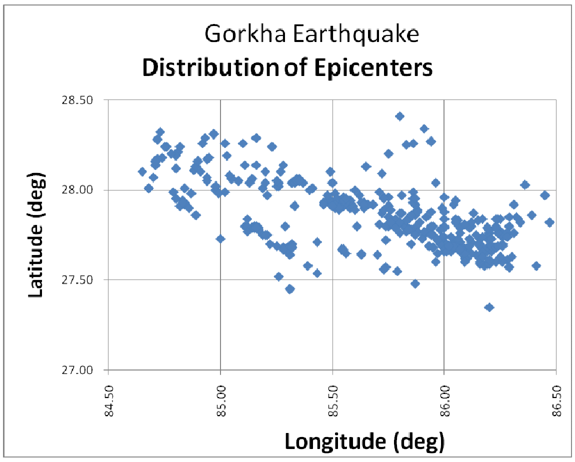

Figure 12 Zone of Epicenters of Gorkha Earthquake

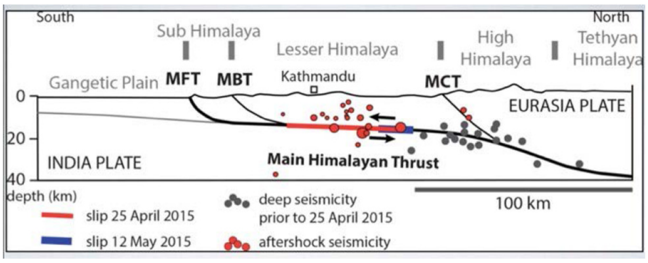

Figure 13 Location of Foci of Gorkha Earthquake in the Cross Section of Nepal Himalayas (Courtesy of GEER Report No. 040, Version 1.0, 29th July 2015)

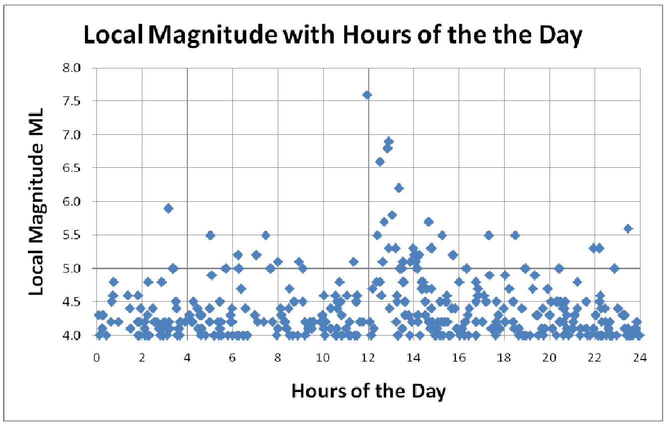

Figure 14 Recorded Aftershocks with Hours of the Day

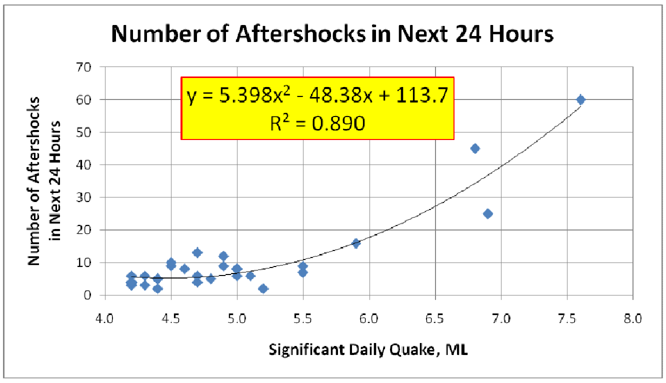

Figure 15 Number of Aftershocks in Next 24 Hour

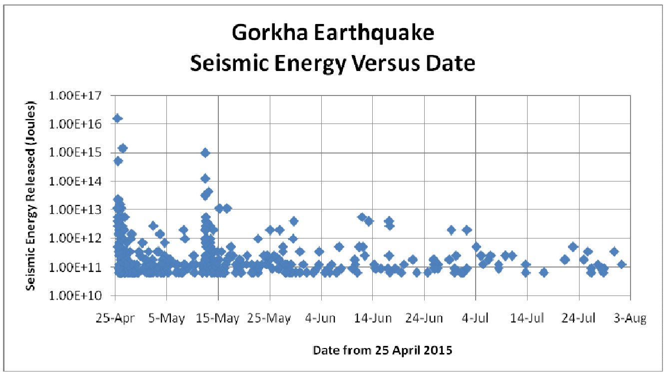

Figure 16 Seismic Energy Release in Gorkha Earthquake Sequence

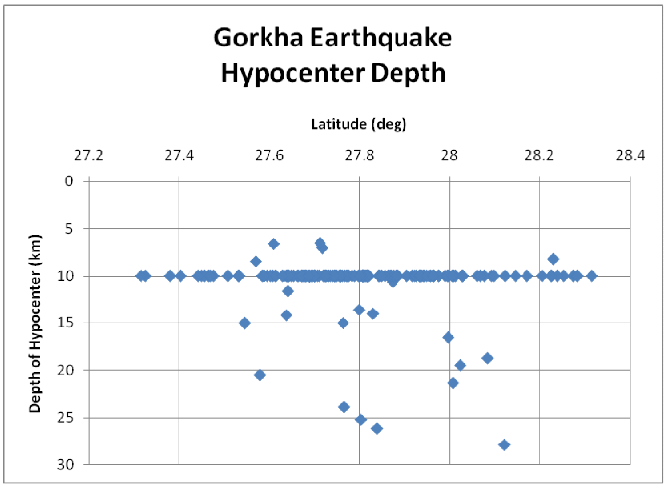

Figure 17 Hypocentral Depths of Gorkha Earthquake Sequence

2.5 Why So Destructive

The earthquake of 25th April of 2015 was destructive due to both the shallow depth (15 km), and the fact that Kathmandu lies in a basin filled with about 500 metres of soft sediment (Figure 18). Sedimentary basins can have a large effect on ground motion above them. Earthquake waves travel at high velocity through the stiff, crystalline rock of the crust and slow dramatically when entering the basin. This increases the amplitude of the earthquake waves within the basin fill. In addition, the sharp density contrast of the soft basin rocks with surrounding material can cause waves to reflect, trapping energy in the basin for a period of time. This extends the duration of shaking during the earthquake.

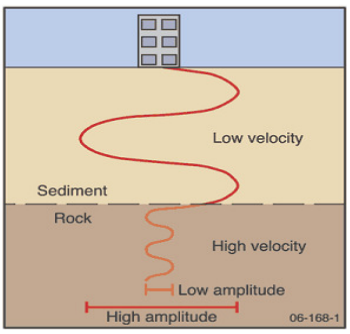

Figure 18 Soil Condition of Kathmandu
(IRIS Education & Public Outreach and The University of Portland)

The ground motion during the earthquake was too strong. A strong motion record from a station KATNP (USGS) is shown in Figure 11. In Figure19, the upper plot shows acceleration, middle shows velocity, and bottom shows displacement of the ground, revealing motion due to elastic seismic waves, but also the finite net southern shift of 1.5 m.

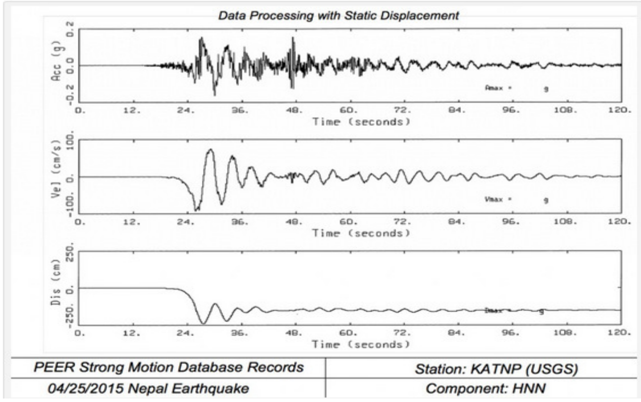

Figure 19 Strong motion record of Nepal earthquake
(PEER Berkeley)

2.6 Damages in the earthquakes

Across many districts of the country, thousands of houses were destroyed with entire villages flattened, especially those near the epicenter. Several of the churches, temples and monasteries in the Kathmandu valley were destroyed. Several pagodas on Kathmandu Durbar Square, a UNESCO World Heritage Site, collapsed, as did the Dharahara tower, built in 1832. The collapse of the latter structure killed at least 180 people. Manakamana Temple in Gorkha district is also destroyed. The northern side of Janaki Mandir in Janakpur was also damaged. Many temples, including Kasthamandap, Panchtale temple, the top levels of the nine-story Basantapur Durbar, the Dasa Avtar temple and two dewals located behind the Shiva Pārbati temple were destroyed by the earthquake. Some other monuments, including the Kumari Temple and the Taleju Bhawani Temple got partially collapsed. The top of the Jaya Bageshwari Temple in Gaushala and some parts of the Pashupatinath Temple, Swyambhunath, Boudhanath Stupa, Ratna Mandir, inside Rani Pokhari, and Durbar High School have been destroyed. In Patan, the Char Narayan Mandir, the statue of Yog Narendra Malla, a pati inside Patan Durbar Square, the Taleju Temple, the Hari Shankar, Uma Maheshwar Temple and the Machhindranath Temple in Bungamati were destroyed by the quake. In Tripureshwar, the Kal Mochan Ghat, a temple inspired by Mughal architecture, was completely destroyed and the nearby Tripura Sundari also suffered significant damage. In Bhaktapur, several monuments, including the Fasi Deva temple, the Chardham temple and the Vatsala Durga Temple of 17th century were fully or partially destroyed.

Outside the valley, the Manakamana Temple in Gorkha, the Gorkha Durbar, the Palanchok Bhagwati, in Kabhre Palanchok district, the Rani Mahal in Palpa district, the Churiyamai in Makwanpur district, the Dolakha Bhimsensthan in Dolakha district, and the Nuwakot Durbar were partially destroyed. The north eastern parts of India also received major damage. Heavy shocks were felt including the states Uttrakhand, Uttar Pradesh, West Bengal and many other states. A huge damage was caused to the property and the lives of the people. Figure 20 to Figure 23 shows images of different damages in the earthquake.

Apart from damages to heritage and historical monuments, a large number of houses have collapsed. The damages to houses have occurred in many districts. In general adobe and brick / stone in mud have collapsed, while properly constructed RCC buildings have mostly survived even in Barpak area, the epicenter of Gorkha earthquake of 25th April 2015.

Figure 20 Damages of some historical places (National Post News)

Figure 21 Damages of superstructures (globalnews.ca)

Figure 22 Damages of Transport system (mormonsoprano.com)

Figure 23 Damages in Everest (www.telegraph.co.uk)

3. CONCLUSION

Nepal is situated in a very active earthquake prone area of Asia and Kathmandu is classified as a highly earthquake prone city of Nepal. The earthquake activity in Nepal is caused by the ongoing continental collision between Indo-Australian plate and Eurasian plates. Earthquake was first recorded in Nepal on June 7th, 1255 AD where one third of the total population in Kathmandu was killed by a 7.7 Richter scale. Recently on Saturday April 25th, a magnitude Mw 7.8 earthquake struck the Gorkha district of Nepal. Over 367 aftershocks have also struck the region including a Mw 5.2 in the mountains causing a landslide. More than 8,000 people died and more than 19,000 people wounded in this earthquake. The disaster caused many buildings in Kathmandu valley to collapse. Thousands of houses were destroyed across many districts of the country, with entire villages flattened, especially those near the epicenter. Several of the churches and pagodas in the Kathmandu valley were destroyed. A major aftershock of magnitude 6.7 M_w occurred on 26th April 2015 in the same region at 12:55 NST (07:09 UTC), with an epicenter located about 17 km (11 mi) south of Kodari, Nepal. A second major aftershock occurred on 12th May 2015 at 12:51 NST with a moment magnitude (M_w) of 7.3 M_w 18 km (11 mi) southeast of Kodari at Sunkhani village of Dolakha district.

4. REFERENCES

"April 2015 Nepal Earthquake"- Wikipedia.

"Earthquake" - Information bulletin Nepal, International Federation of Red Cross and Red Crescent Societies.

IRIS Earthquake Browser (*www.iris.edu/ieb*)

"List of Earthquakes in Nepal"- Wikipedia.

"Magnitude 7.8 NEPAL"-IRIS Education & Public Outreach and University of Portland.

"M 7.8 Nepal Earthquake of 25 April 201 5"- U.S. Department of the Interior U.S. Geological Survey.

National Seismological Center, Department of Mines and Geology, National , Kathmundu, Nepal, http://www.seismonepal.gov.np/Geotechnical Extreme Event Reconnaissance, GEER Assocaition Report No. GEER-040, Version 1.0, 29th July 2015

"Nepal Earthquake overview"-USAID (4-25-2015).

"Nepal Earthquake Iom Emergency Response"-Situation Report, (30 April 2015).

"Nepal and Natural Disaster"-United Nations Human Settlement Program.

"Nepal Situation Report #2"-Humanity Road – (Activation: Nepal Earthquake- Glide EQ-2015-000048-NPL Publication Date: April 26, 2015 (local Social Media Situation Report).

Ranjan Kumar Dahal-"Geology of Nepal"-(Lecture Note), Department of Geology, Tribhuvan University, Ghantagar, Kathmundu, Nepal.

Samyog Shrestha-"Probabilistic Seismic hazard Analysis of Kathmandu City, Nepal", International Journal of Engineering Research and General Science Volume 2, Issue 1, January 2014 ISSN 2091 -2730.

Sujan Malla, Dr. Eng., Structural Engineer, Zurich, Switzerland, Version 0, 20th June 2015