Situation of damage in and around Kathmandu Valley due to the 2015 Gorkha Nepal Earthquake

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An earthquake with a moment magnitude of 7.8 occurred at 11:56 NST (local time) on 25 April 2015, in the central part of Nepal (Gorkha). A damage survey was conducted at the affected area during 26 May to 21 July three times by the team of NIED. This paper outlines the findings of this survey on the various aspects of the earthquake disaster in the Kathmandu Valley and surroundings. Some of the observations are that the main damage was to masonry buildings especially with mud mortar, and limited to RC buildings. Smaller damage was shown at the historical buildings with renovation. Thus, low cost retrofitting method will be necessary for mainly in suburb housings rich in masonry buildings with mud mortar. A comparison with the past risk assessment project results (JICA, 2002), the similarity between damage features in the 1833 earthquake and the 2015 Gorkha Nepal Earthquake. These may help the future earthquake disaster mitigation efforts.

Key Words : *Kathmandu Valley, damage estimation, scenario earthquake, building structure*

1. INTRODUCTION

An earthquake with a magnitude of 7.8 (M_w) occurred at 11:56 NST, (local time) on 25 April 2015, in the central part of Nepal (Gorkha). The epicenter was east-southeast of Lamjung, 77 km south-west of Kathmandu, 28.15 degrees at the north latitude and 84.71 degrees at the east longitude, and the depth was 15 km (USGS). The Nepal Police reported on 22 June the number of deaths 8,660 and injured 21,952 for the main shock and deaths 172 and injured 3,470 for the aftershock. It was also reported that more than 500,000 buildings and houses were damaged and about half of those had which collapsed. In Kathmandu Valley, around 1,900 people were killed and 50,000 buildings collapsed.

This earthquake was officially named as The 2015 Gorkha Nepal Earthquake, since the hypocenter was located in the Gorkha region.

A major aftershock with a moment magnitude of 7.3 (M_w) occurred at 12:51 NST on 12 May 2015. The epicenter was 75 km north-east of Kathmandu and near the Chinese border, 27.82 degrees at the north latitude and 86.08 degrees at the east longitude, and the depth was 19 km (USGS).

The National Research Institute for Earth Science and Disaster Prevention (NIED) organized a damage survey team and dispatched it to the affected area during 26 May to 3 June, 17 to 24 June and 16 to 21 July for the investigation into the damage and collection of information and data. This paper outlines the findings of this investigation under-taken by this team on the various aspects of the earthquake disaster in the Kathmandu valley (**Fig. 1**).

During "The Study on Earthquake Disaster Mitigation in the Kathmandu Valley of Nepal" (JICA, 2002) [1)], seismic hazard and damage assessment as

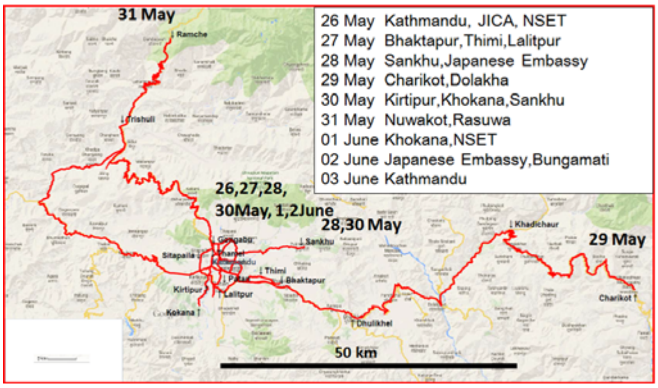


Fig.1 Survey Route

well as earthquake disaster management planning were conducted. In the study, four scenario earthquakes have been set including the 1934 Bihar earthquake recurrence, though the 2015 Gorkha earthquake was not considered. To compare the study results with the phenomenon caused by the Gorkha earthquake is one of the issues to be investigated.

2. SEISMIC CONDITION

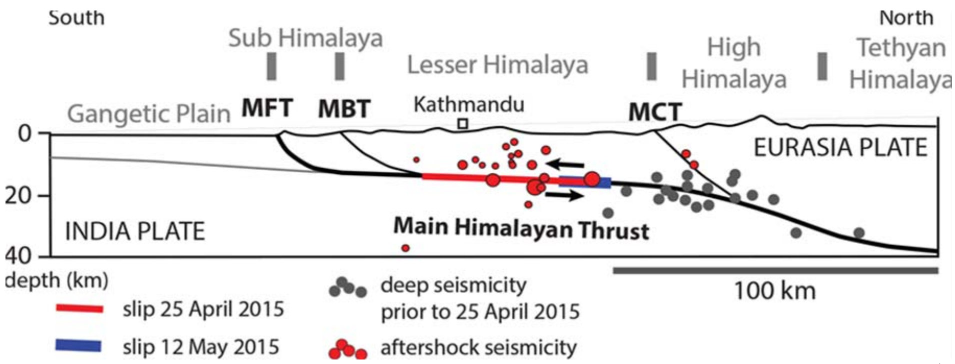


Fig.2.1 Cross-section of the Main Himalayan Thrust (USGS: The April-May 2015 Nepal Earthquake Sequence) [2]
Generalized cross section showing the approximate locations of slip during the 25 April and 12 May 2015 ruptures on the Main Himalayan Thrust, and approximate aftershock locations of both events. MFT = Main Frontal Thrust, MBT = Main Boundary Thrust, MCT = Main Central Thrust. Cross section generalized after Lave and Avouac, 2001[3] and Kumar *et al.* , 2006[4].

(1) Seismo-tectonic information of the 2015 Gorkha Nepal Earthquake

The India plate subducts along the Main Himalayan Thrust beneath the Eurasian plate. Among the most dramatic and visible manifestations of plate-tectonic forces are the lofty Himalayas, located where the two large landmasses of India and Eurasia collide as a result of plate movement. Because the rock densities of both of these continental landmasses are roughly the similar one cannot easily subduct under the other[2]. Thus, the Main Himalayan Thrust dips at a relatively low angle (6° - 14°) towards north (Mukhopadhyay, 2014)[5]. Tectonics of the Himalaya region are expected to continue to rise at an uplift rate of more than 1 cm/yr.[2]

(2) The risk assessment results of JICA 2002

During “The study on earthquake disaster mitigation in the Kathmandu Valley (JICA, 2002)[1]”, hazard and damage analyses were conducted. The ultimate purpose of this earthquake disaster analysis was to recognize phenomena associated with a future earthquake in the vicinity of the Kathmandu Valley. Based on the assessment results caused by the scenario earthquakes, a disaster prevention plan can be established. The scenario earthquake fault models are shown in **Fig. 2.2**.

Nepal lies on an active seismic zone ranging from Java –Myanmar – Himalayas – Iran and Turkey, where many large earthquakes have occurred in the past. The historical earthquake catalogue shows the high seismicity along the Himalaya and also the occurrence of huge earthquakes. Kathmandu has suffered damage due to earthquakes several times, including the 1934 Bihal-Nepal earthquake that caused one of the most serious damages to the Kathmandu Valley in the past. Earthquake damage will differ depending on the type and location of the earthquake will be different depending on the type and location of the earthquake, such as a huge earthquake outside of the Valley and a small to middle-scale one within the Valley. In the study, four scenario earthquakes have been set, including the 1934 Bihar earthquake recurrence.

1)1934 earthquake (M_w 8.4)
2)Mid Nepal Earthquake (M_w 8.0)
3)North Bagmati earthquake (M_w 6.0)
4)Kathmandu Valley local earthquake (M_w 5.7)

The First case is the 1934 Bihar earthquake (M_w

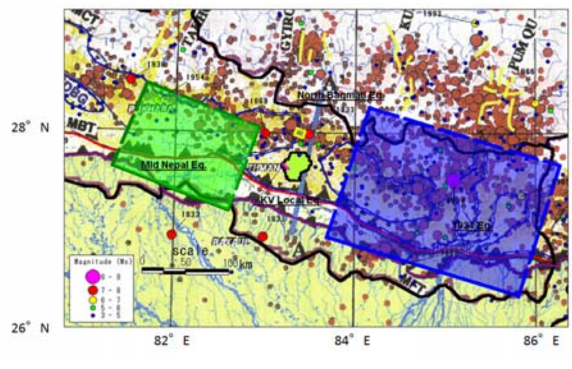


Fig.2.2 The scenario earthquake fault models (JICA2002)

8.4) model, whose fault model is shown as the blue square area. The second case is namely the Mid Nepal Earthquake (M_w8.0), which was the most devastating one which lies west of Kathmandu as the seismic gap area shown in green. The third model is the seismically active with small earthquakes in the near northern part of the Kathmandu Valley which is shown in red. The last model is based on the lineament at base rock in the Kathmandu Valley, as small as magnitude 5.7 (M_w).

2.3 Comparison of the study results and this earthquake phenomenon

The scenario earthquakes of the study did not consider the 2015 Gorkha Nepal Earthquake, and the Mid Nepal earthquake was estimated as larger damage to the Kathmandu Valley. However, the seismic intensity and damage estimated for the North Bagmati case, which locates near the largest aftershock with a moment magnitude of 7.3 (M_w) on 12 May 2015, is corresponding with the current earthquake. The seismic intensity is VII of MMI scale, and the death around 2,000.

Secondly the damage and death due to the current earthquake were concentrated in and around the Kathmandu Valley even though the epicenter was 80km away west from the Valley. **Fig 2.3** shows the death rate distribution.

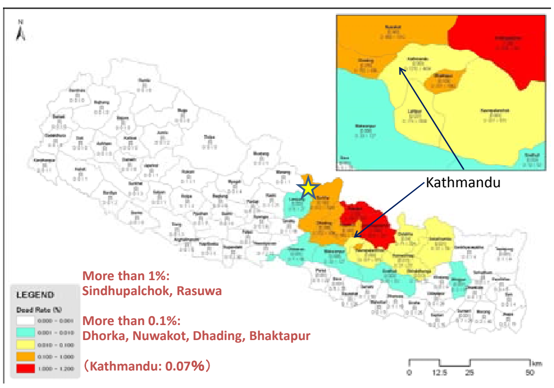


Fig.2.3 Dearth Rate due to the 2015 Gorkha Earthquake (after the Nepal Police data in its web site at June 22)

Looking at the seismic source, the high-frequency component radiation area by Yagi's model is explaining this issue. **Fig.2.4** shows earthquake rupture model for the 2015 main shock (Yagi and Okuwaki, (2015) [6,7]). This model inverted teleseismic P-wave data applying a novel formulation that takes into account the uncertainty of Green's function by using Yagi and Fukahata (2011) [8], which uses waveform inversion from the IRIS (Incorporated Research Institutions for Seismology) [9] waveform (time-series) data. The fault length and width of the rupture plane are east-west 150 km long, including Kathmandu and the region from north to south 120 km.

The major slip, shown by contour and red colored with maximum slip of 4.1m and east-south-east away from epicenter, locates around the Kathmandu Valley. And the area of major high-frequency (1Hz) seismic radiation, shown by pink rectangular, extended north of slip distribution, near the North Bagmati scenario earthquake model. It can be an idea that the major high-frequency component radiation might close relation with the damage to buildings and housing in the Kathmandu Valley and around due to the current earthquake.

Further, the damage features estimated for the North Bagmati earthquake by the 2002 study is close to the one by the current earthquake.

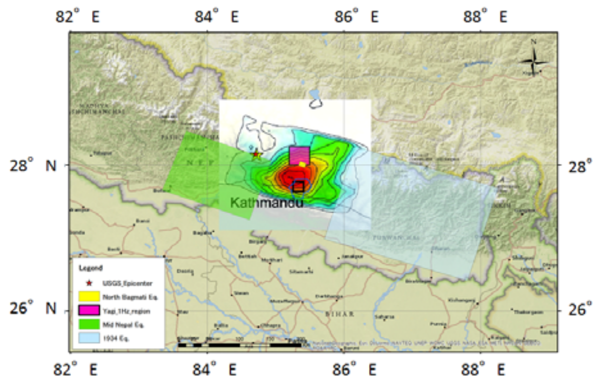


Fig.2.4 Source Model of 2015 Gorkha Nepal Earthquake (*after* Yagi, *et al.* [6,7,8])

2.4 The 1833 and the 2015 earthquake

The 2015 Gorkha Earthquake is locating between the 1934 Bihar Earthquake and the big Seismic Gap west of Kathmandu or Pokhara. However, according to the historical earthquake information, it is similar to the 1833earthquake [10]. The similarity is source area, magnitude class, damaged area and damage features. Even in and around the Kathmandu Valley is the main damaged area, liquefaction is sparse, and building damage was 1,972 (50-60%), deaths 42 (around 0.2%). If there exists almost similar typology of buildings in the Katmandu Valley, such as stone and adobe and brick with mud mortar, the current earthquake damage in Kathmandu Valley will be appeared such as building damage 40%, and fatality will be 0.2% [11]. Then there will be similarity between the 1833 and the 2015 earthquakes. This kind of information will help the future earthquake disaster management in and around the Kathmandu Valley.

3. DAMAGE IN KATHMANDU VALLEY

There were many building damage in the Kathmandu Valley, Bhaktapur, Lalitpur / Patan, Kathmandu, Madhyapur Thimi and Sankhu are highlighted.

(1) Bhaktapur

"*Bhakta*" means Devotee in Sanskrit, and "*pur*" means city. Thus, "*Bhaktapur*" is the city of devotees. The center areas of these palaces are called "*Durbar Square*". Bhaktapur's Durbar Square is a conglomeration of pagodas and many of Sikhara style temples in Bhaktapur's Durbar Square were severely damaged (**Fig.3.1**).

The steel frame reinforced Chayslin Duga temple (**Fig. 3.2*a***). This temple was not damaged. During the 1934 earthquake Chyasilin Mandap was completely destroyed. The architects Götz Hagmüller and Niels Gutschow set about rebuilding this temple using metal reinforcements via GTZ funding. The Vatsala temple (**Fig. 3.2*b***: center and **Fig. 3.2*c***), which is a Newar style temple, was established *ca.* A.D. 1690, but destroyed. Yaksheshvara temple (**Fig. 3.2*b***: right) survived.

Fig.3.1 Bhaktapur before / after the earthquake (Photo. by T. Ohsumi), before / after the 1934 earthquake in Bhaktapur (Courtesy of MoHA)

Fig.3.2 Reinforced Chayslin Duga temple (*a* and *b*: left) by steel frame, Vatsala temple (*b*:center and *c*) was destroyed and Yaksheshvara temple (*b*:right) survived, before / after 2015 earthquake in Bhaktapur (Photo. by T. Ohsumi).

One of the temples in Bhaktapur collapsed in the 1934 earthquake, and has not been rebuilt (**Fig. 3.3**). If the reconstruction of historical buildings that have been lost during earthquakes does not proceed, this will be a major blow to future developments in Nepal's tourism-oriented country.

Fig.3.3 This temple in Bhaktapur collapsed in 1934 earthquake, but has not been rebuilt (Photo. by T. Ohsumi).

(2) Lalitpur/ Patan

Patan is "*Lalitpur*" in Sanskrit, is called "*Yela*" in Newari, it means the city of beauty. The Patan palace was renovated with assistance from the Kathmandu Valley Preservation trust (KVPT) and the Sumitomo Foundation in 2013(**Fig. 3.4**). Thus, in Patan, after the earthquake, this place had only partial damage at top of structure parts (Gajur and Baymvah) (**Fig. 3.5**).

(3) Kathmandu

The old palace structures in Kathmandu's Durbar Square, which had not undergone renovations, had severe damage during the earthquakes (**Fig. 3.6**). In the photo on the left, the white structure is about 150 years old, built during the Rana Dynasty. In the photo on the right side, the four-tiered brown temple is about 300 years old, constructed during the Gorkha Dynasty.

At places along the Kathmandu Ring Road, reinforced concrete (RC) frame buildings were damaged by tilting; however, most of the building damage in the city occurred in masonry buildings. At Gongabu, northwest of the Ring Road, many RC buildings were damaged; most of these were four to seven story structures or soft storied buildings. The damage was sometimes greater at locations with soft ground such as deltaic deposit near river branches (**Fig. 3.7**); however, some damage was also likely to have been caused by inappropriate construction methods. At Sitapaila, west of the Ring Road, some RC building collapsed at locations where the ground conditions on terraces were a bit stiff. At Balkhu, southwest of the Ring Road, RC frame buildings were tilted. This is near the confluence of the Bagmati and Balkhu rivers, where collapsed buildings fell onto and destroyed a neighboring building (**Fig. 3.8**). The ground conditions in Balkhu were soft because of the presence of riverbed sediments.

Fig3.4 Renovation of the structure and the cover of the roof was carried out in 2011.
a: top left Installation of timber rafters, *b*: hand wood planking, *c*: waterproof membrane, *d*: traditional terracotta roof tiles on a mud-bed (from Information plate of Patan Museum).

Fig3.5 In Patan, after the earthquake, this place (*a*) had partial damage at top of structure parts (Gajur and Baymvah) (*b*) (Photo. by T. Ohsumi).

Fig.3.6 Kathmandu Durbar Square after the earthquake (*a*), before the earthquake (*b*) (Photo. by T. Ohsumi)

Fig.3.7 At Gongabu, RC frame buildings were tilted (*a*,*b*). A shear crack in the first flower (*c*)

(Photo. by T. Ohsumi)

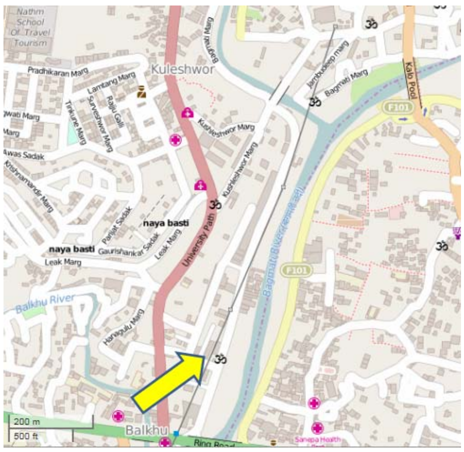
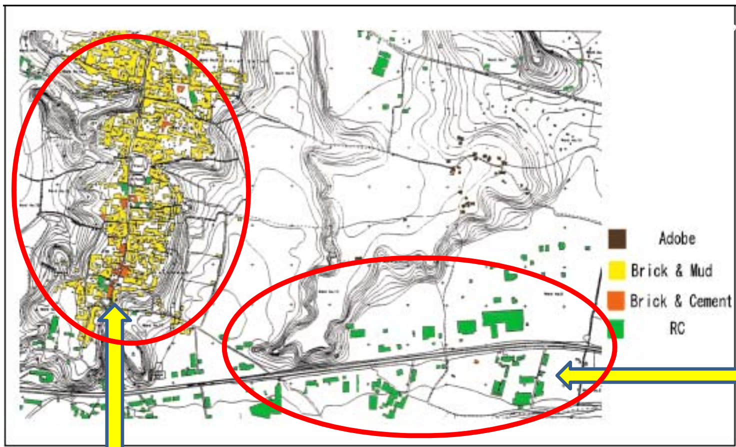


Fig.3.18 At the branch point of the Bagmati River and the Transformor River, collapsed building fell onto and destroyed the next building (Photo. by T. Ohsumi).
OpenStreetMap https://www.openstreetmap.org/



JICA 2002

a

b

Fig. 3.9: The building type classification map in Thimi, Newer building area (*a*) and core area (*b*)
(Photo. by T. Ohsumi)

(4) Madhyapur Thimi

In the JICA (2002) report, building types were classified for the whole Katmandu. The investigation was mainly based on visual observations (**Fig.3.9** upper). In newer building areas (**Fig.3.9** *a*), the damage has been reduced in the building of the RC structures. The core area located on a small hill (**Fig.3.9** *b*), the houses had been destroyed in 1934 rebuilt and again received severe damages .

(5) Sankhu

Sankhu is an old town and locating on a small hill in the north east part of the Kathmandu Valley. Houses damaged by the earthquake have been demolished with the support of Canadian Forces relief operations in Sankhu. Heavy equipment was brought for this purpose from Canada. In general, RC buildings were partially damaged, whereas masonry buildings were severely damaged.

The difference in damage as a result of building type was remarkable. Damage in Sankhu was extensive. Brick and cement mortar houses without RC columns experienced a lot of damage. In contrast, the damage to RC structures – particularly those erected in recent years – was generally minor. These structures were mainly five to six story buildings. In contrast, many of the non-engineered masonry structures that experienced complete collapse or partial damage were two to four story buildings in Sankhu (**Fig. 3.10:** left). Damage in non-engineered masonry structures was initiated by vertical cracks in the corners of the buildings (**Fig. 3.10:** *a*), which contained no RC columns (**Fig. 3.10** *b*). The outer wall structures of such buildings were generally burned brick with cement mortar joints to withstand rain. In several cases, the inner walls of buildings are adobe bricks with mud mortar.

Fig.3.10 The damage to RC structures was generally minor.These structures were mainly five to six story buildings. Many of the non-engineered masonry structures that experienced complete collapse or partial damage were two to four story buildings in Sankhu (*left*). Damage in non-engineered masonry structures was initiated by vertical cracks in the corners of the buildings (*a*), which contained no RC columns (*b*). (Photo. by T. Ohsumi).

4. LANDSLIDES

A numerous huge slope failures which occurred in the mountainous area buried villages and valleys, and provided the loss of many lives. We visited a landslide zone in Ramche, and it is located in the northwest of Kathmandu city in a mountainous area. Many of fallen rocks were on the roads, also we encountered a bus that hit by falling rocks (**Fig. 4.1**). Thick talus is deposited in the landslide area in Ramche, in Rasuwa district (**Fig. 4.2**). The town is located at an altitude of 2,060 m. There are houses that had been caught in a landslide, but the damage was limited. However, the whole scope of the slope failures is not clear at the present time, because any detailed and total survey in the mountainous area has not been carried out. Thus, causalities will in-crease as they are found.

Fig. 4.1 Bus was hit in falling rocks in Dhikure,on Baglung Rajmara High way. (Photo. by T. Ohsumi)

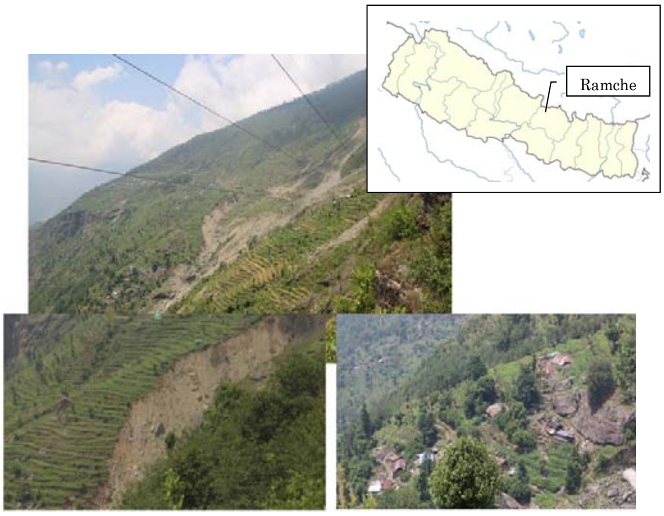


Fig.4.2 Thick talus is deposited in the landslide area in Ramche. (Photo. by T. Ohsumi)

5. SUBURBS AND RURAL AREAS

The number of casualties was concentrated to the northeast of Kathmandu Sindhupal Chok district. We visited at Charikot, in the Bhimeshwar Municipality, roughly 50 km east of Dhulikhel. The town is located at an altitude of 1,550 m. The name of the district Dolakha came from Dolakha Town, which is situated northeast of the capital Charikot. These areas had many casualties. According to the locals, the large aftershock felt stronger than the main shock. This is understandable as the aftershock's hypocenter is located just below this area. Many houses collapsed in the aftershock (**Fig. 5.1** *a*).

Urban and rural housing is significantly different. In the suburban and rural areas where there are many stone houses, a lot of damage occurred. The collapse of heavy stones used in house construction, resulted

According to the Nepal Police statistics as of 22 June 2015, more than 500 thousand buildings and houses were damaged – and about half of those collapsed; that number is now increasing (**Fig.5.2**). First, the dominant rural housing style in the area consists mainly of stone or adobe masonry as well as mud mortar masonries[11]. The collapse of heavy stone buildings killed many. The damage to houses in the mountainous region was typically concentrated in non-engineered structures. In rural areas, unreinforced masonry, sourced from regionally available

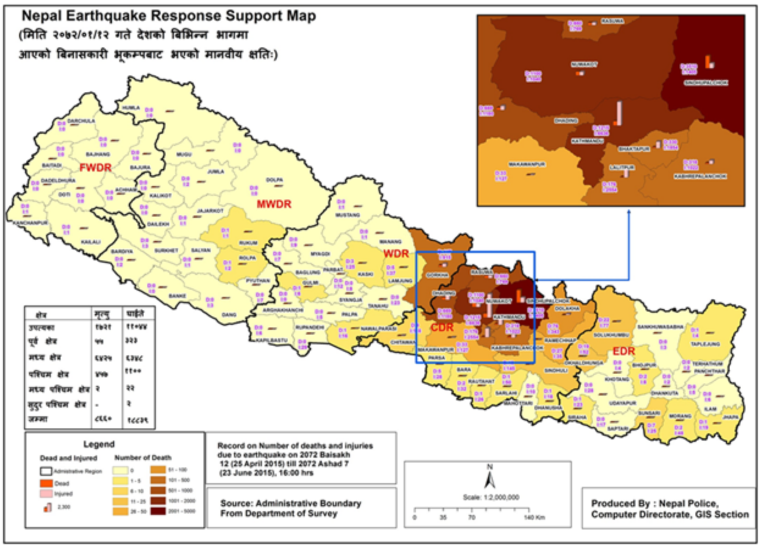
directly in deaths and property destruction.

In Dolakha district, adobe style houses collapsed. Primarily, adobe houses collapsed as a result of cracks in the gables and corner foundations as a result of ground motion. Many adobe style houses were broken at their gables (**Fig. 5.1** *b*). Stone houses could also collapse as a result of delamination. Stone style houses also collapsed by delamination.
materials, was the main construction material. Regardless of the masonry material used, serious damage occurred with houses as a result of masonry cemented with mud mortar. This housing construction method also exists in urban areas, primarily for constructions undertaken more than 30 years ago. In the rural areas, this type of housing is still the most popular method of housing construction. Thus, the retrofitting of low-cost earthquake-damaged housing without the consideration of engineering standards is a key issue.

a

b

Fig.5.1 Adobe style houses (*a*) and Stone style house (*b*) in Charikot, (Photo. by T. Ohsumi)



22 June :
Death 8,660
Injured 18,839

Aftershock
Death 172
Injured 3,470

Fig.5.2 Casualties and injured people by Nepal Police as of June 22, 2015

7. FINDINGS

1) Although RC buildings were partially damaged, the difference in damage between buildings with and without RC appears remarkable. Brick and cement mortar houses without RC columns generally had a lot of damage. Structures having no RC columns in the corners generally experienced vertical cracking in the brick masonry walls.
2) Along the west side of the Kathmandu Ring Road, RC frame buildings were damaged in some cases by during the 2015 Gorkha Nepal Earthquake. The building damage might be caused by the soft ground conditions near the river branch as well as inappropriate construction methods.
3) The casualties resulting from the earthquake were concentrated in the northeast of Kathmandu in the Sindhupalchok district. Many houses here collapsed in the aftershocks. The casualties were compounded by significant differences in urban and rural housing typology. In suburbs and rural areas, more than 80 % of stone, adobe and brick with mud mortar houses that were badly damaged. The collapse of heavy masonries used in house construction took many lives.
4) The three royal palace complexes in the Kathmandu valley (Kathmandu, Bhaktapur, and Lalitpur / Patan) had undergone significantly different renovation works over the last few decades (although not for the historic structures within the old royal palaces). This enables a means to assess how particular renovations can strengthen historical structures.
5) In rural areas, stone masonry is used as a current building technique. Retrofitting such low-cost non-engineered housing is a key issue.
6) The major high-frequency (1 Hz) seismic radiation might cause the damage to buildings and housing in and around the Kathmandu Valley.
7) The major high-frequency (1 Hz) seismic radiation caused much of the damage to buildings and housing on the north side of the Kathmandu Valley.

Nepal and Japan have a long history of cooperation in earthquake engineering. Many joint research projects have been carried out in the academic field for earthquake disaster mitigation. 2016 is the 60th anniversary of the establishment of diplomatic relations between Nepal and Japan. All of the members of our team wish to strengthen the partnership in earthquake engineering that has been developed between Nepal and Japan through ongoing cooperation in investigations of this earthquake disaster and through future joint research projects.

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