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# Lessons Learned from the Nepal Earthquake 2015

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**ABSTRACT:** Nepal is one of the most earthquake prone regions in the world as it lies at the boundary of the actively converging Indo-Australian plate and Eurasian Plate. Most of the infrastructure in Nepal were constructed by individuals based on their own needs and budget without consulting engineers, and several studies have shown that many of these structures are likely to be inadequate in resisting earthquake forces. Though an earthquake design code is present in Nepal, it is not mandatory in every part of the country and people do not follow it properly even where it is mandatory.

This paper presents a summary of the reconnaissance survey of a major earthquake of magnitude 7.8 (on 25th of April, 2015) with epicentre in Gorkha District in Nepal, followed by a series of aftershocks including magnitude of 7.3 on the 12th of May 2015. This has resulted in 8969 casualties to date and about 900,000 houses and temples were damaged (partially and completely) leaving thousands of people homeless. Problems associated with the current practices in Nepal are discussed in detail and some suggestions are made for improvements in design and construction. Some of the major problems highlighted in the paper include code compliance, quality control in construction, and lack of preparedness.

## 1 INTRODUCTION

Nepal is one of the most earthquake-prone countries in the world and has experienced a major earthquake approximately every few decades. A major earthquake of magnitude 8.4 occurred in eastern Nepal in 1934 and took more than 10,000 lives in Nepal. Many structures and heritage sites, including Dharahara, were damaged by that earthquake. Other major earthquakes in Nepal which caused severe casualties and physical losses were in 1833 (M7.8 in Kathmandu), 1966 (M6.0 in Bajhang), 1980 (M6.5 in Bajhang), and 1988 (M6.6 in Udayapur) [(Bilham 2004), (Dahal et al. 2013)].

Nepal lies at the junction of the Indo-Australian plate and Eurasian tectonic plate, as shown in Figure 1, which are converging at a relative rate of 40-50mm/year (USGS 2015). The northward movement of Indo-Australian plate beneath the Eurasian plate has caused numerous major earthquakes in the Himalayan region including the M8.0 Nepal-Bihar Earthquake in 1934 and the M7.6 Kashmir Earthquake in 2005.

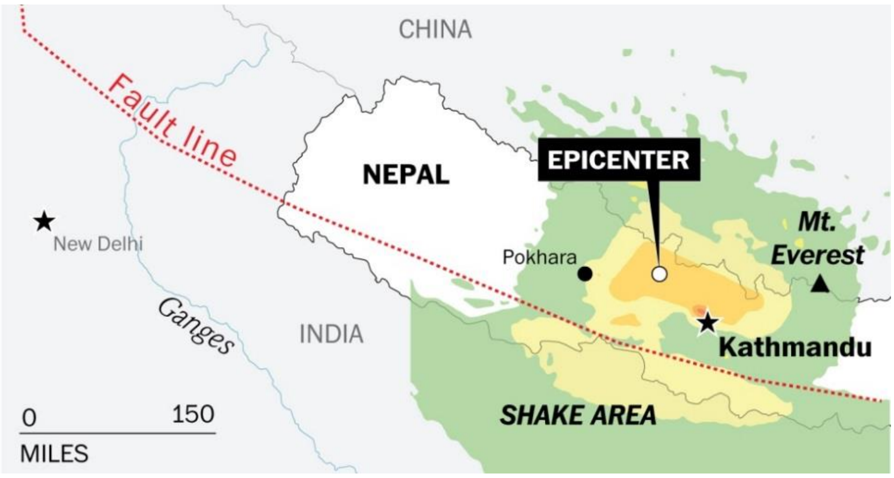


Figure 1: Epicentre of the major earthquake with fault line between Indo-Australian Plate and Eurasian Plate (USGS 2015)

On midday Saturday, the 25th of April 2015, a M7.8 earthquake struck Nepal with the epicenter in the Gorkha District, about 80km northwest of Kathmandu. The rupture spread eastward (towards Kathmandu) over a length of about 120km as shown in Figure 2. The earthquake resulted from thrust faulting between the subducting Indo-Australian plate and the Eurasian tectonic plate and the location of the rupture is shown in Figure 3. This earthquake was followed by a series of several aftershocks, among which four were greater than magnitude 6.0, including M7.3 on the 12th of May. There are 8897 deaths and 22309 injuries reported so far. It is estimated that the lives of one third of the country's population is impacted by this earthquake (NPC 2015). About 900,000 houses have been either destroyed or extensively damaged rendering thousands of people homeless. Figure 4 and Figure 5 show the damage distribution in different districts of Nepal.

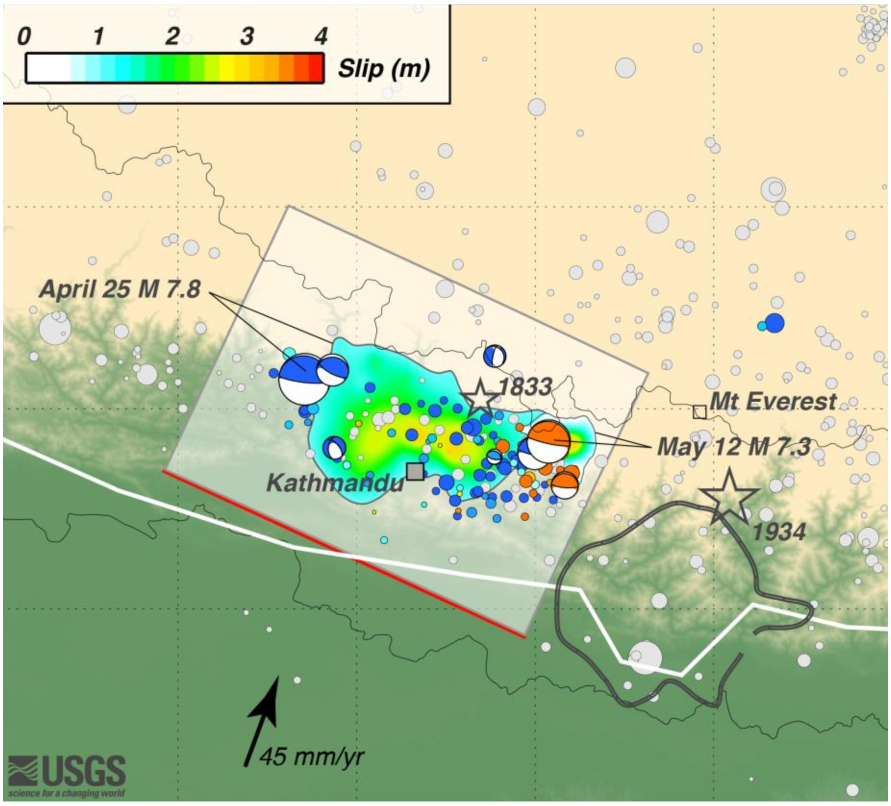


Figure 2: Mainshock slip directed east from hypocentre. The peak slip was about 4m and the dimensions were 120x80km (USGS 2015).

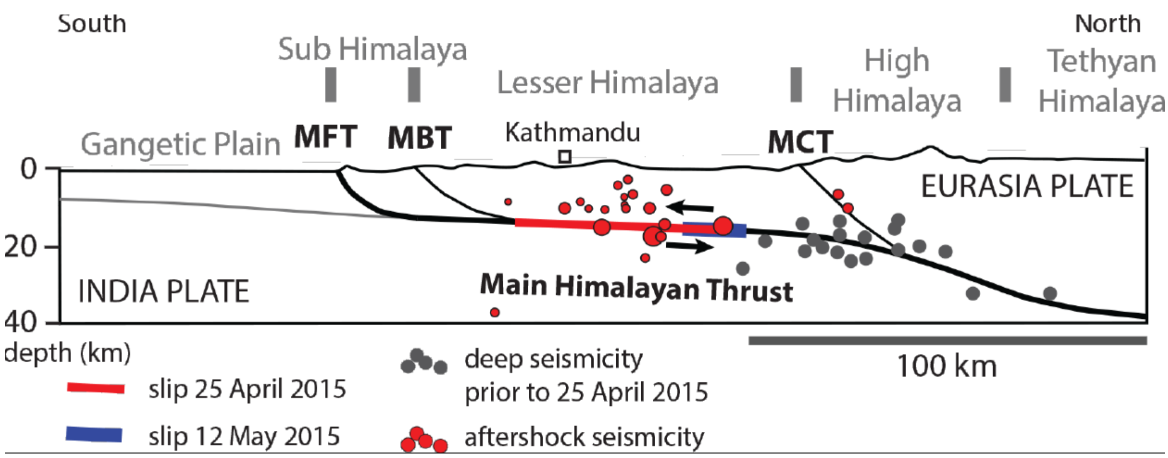


Figure 3: Approximate locations of slip during the 25 April and 12 May ruptures. (MFT: Main Frontal Thrust, MBT: Main Boundary Thrust, MCT: Main Central Thrust) (USGS 2015)

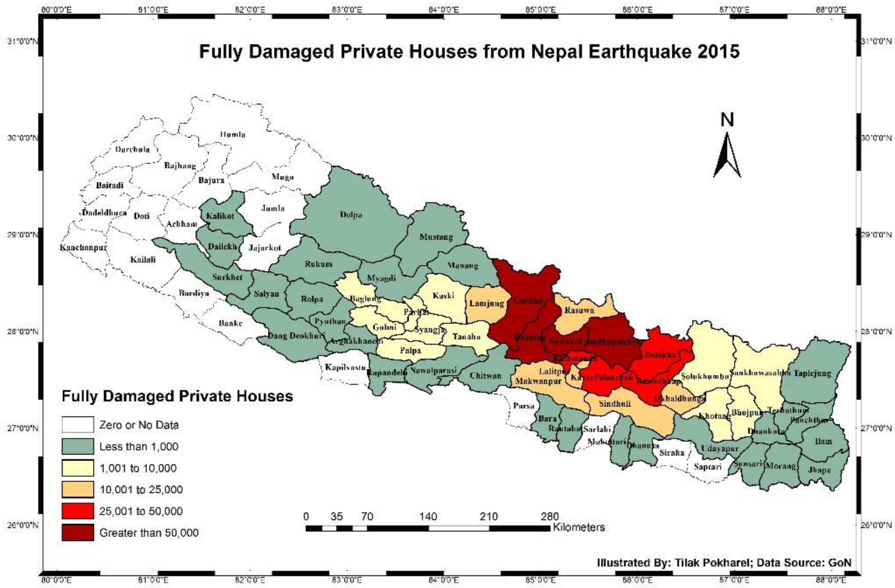


Figure 4: Fully damaged private houses from Nepal Earthquake 2015

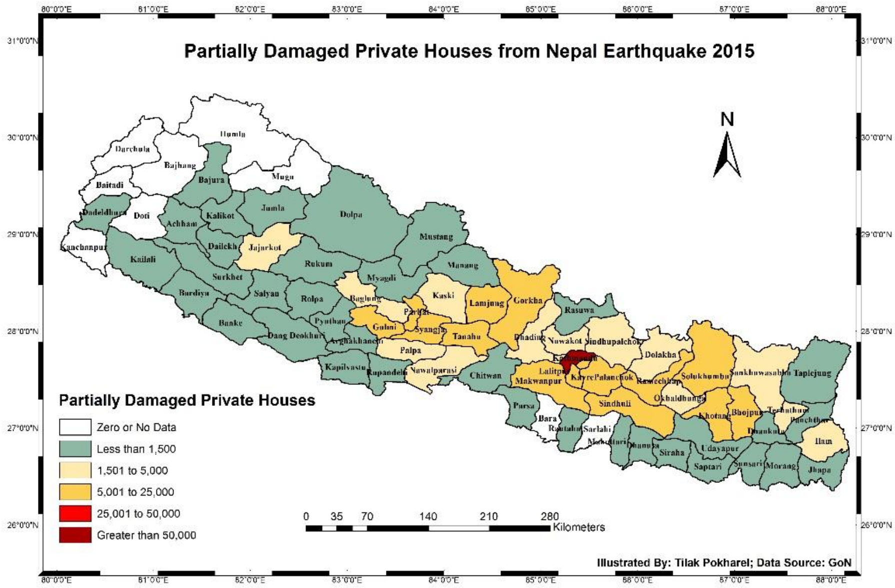


Figure 5: Partially damaged private houses from Nepal Earthquake 2015

The damage caused by the earthquake exposed the weakness of the structures that were not properly designed or constructed in accordance with the building code. The towns and cities were less affected than poorer and rural areas because of the inferior quality of construction in the poorer areas. This paper describes the problems associated with current design and construction practice in Nepal with some possible suggestions to overcome those.

## 2 GROUND MOTION:

There is very limited information about the ground motion for this earthquake. Figure 6 shows the ground acceleration of the M7.8 earthquake on April 25 recorded by USGS at Kathmandu on a soft soil site. The maximum acceleration recorded was less than 0.2g in each direction.

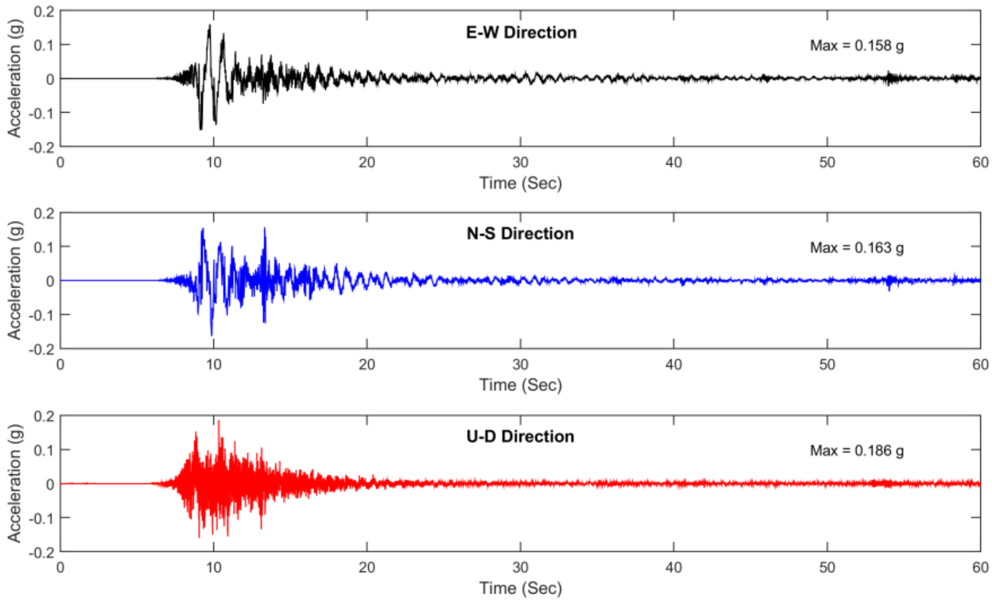


Figure 6: Accelerogram for main event on soft soil (Source: USGS)

Figure 7 shows the spectral acceleration and displacement of the earthquake. The dominant period of the ground motion was observed at 4.52 seconds in the E-W direction, 0.52 sec and 4.80 sec in the N-S direction. The spike in the spectral acceleration in the N-S direction at a period of 0.52 sec is not in the E-W direction, suggesting that there were some directivity effects in Kathmandu due to the nature and location of the rupture. The peak spectral displacement was found to be nearly 300cm and 280 cm in the E-W and N-S directions respectively at 5% damping.

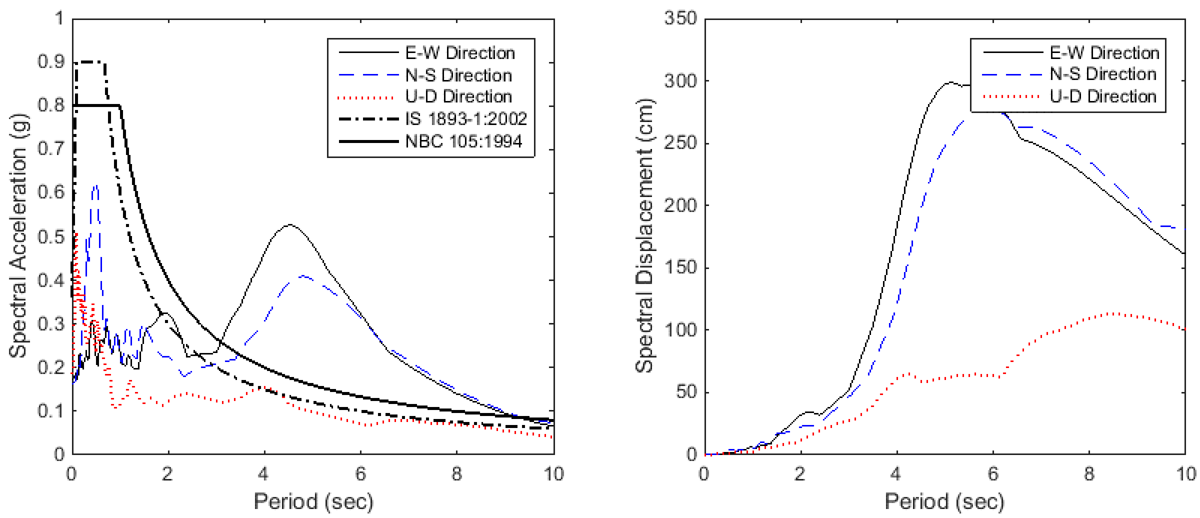


Figure 7: Spectral acceleration and displacement for main event on soft soil

Figure 8 and Figure 9 show the acceleration ground motion caused by the M7.3 aftershock on the 12th of May on soft soil and hard rock sites in Kathmandu respectively. The ground acceleration and displacement in that earthquake was observed to be much smaller relative to those recorded in Kathmandu during the main event on the 25th of April.

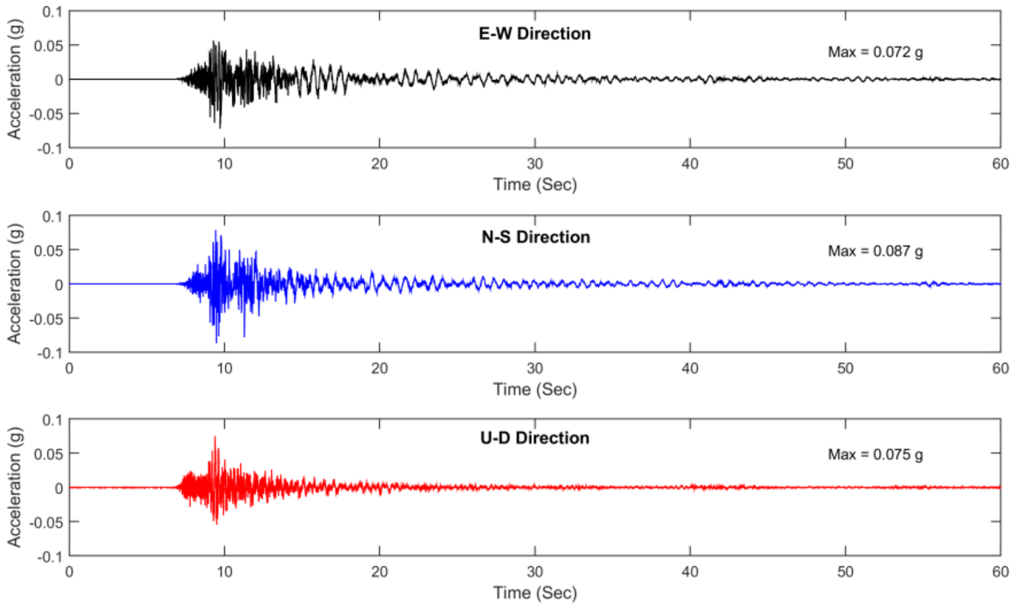


Figure 8: Accelerogram of 12 May aftershock on soft soil (Source: USGS)

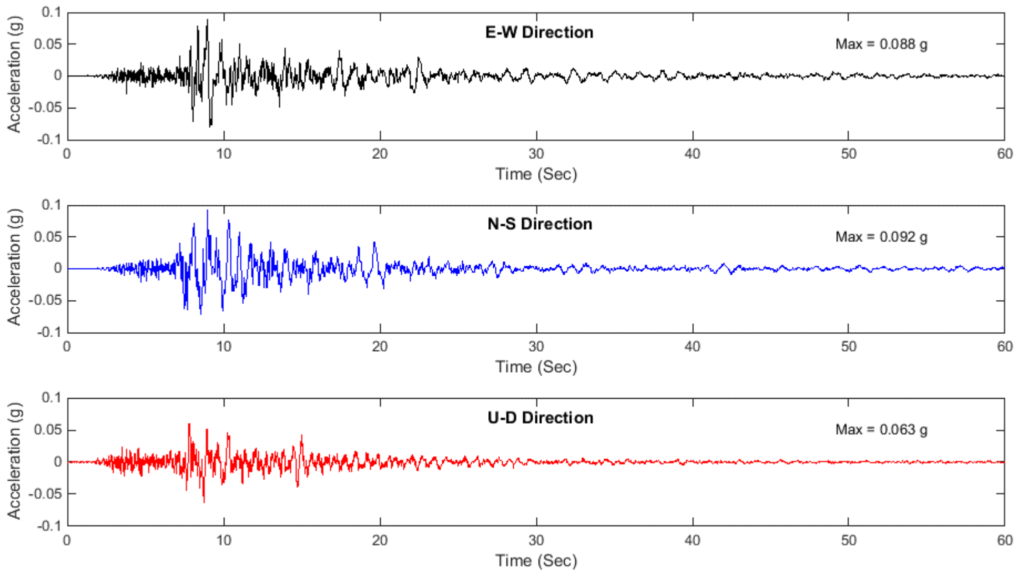


Figure 9: Accelerogram of 12 May aftershock on hard rock (Source: NSET)

The acceleration spectra for the hard rock and soft soil sites are compared in Figure 10 for the same M7.3 earthquake. There is a huge difference in spectral acceleration profiles. There is a second peak around 3 sec on soft soil which is because of the site period of the underlying soft layer. As expected, the second peak is missing in the spectral acceleration profile on the rock site.

Figure 11 compares the spectral displacement on soil and rock sites. Clearly, the spectral displacement on the soft soil is very large compared to that on the rock site.

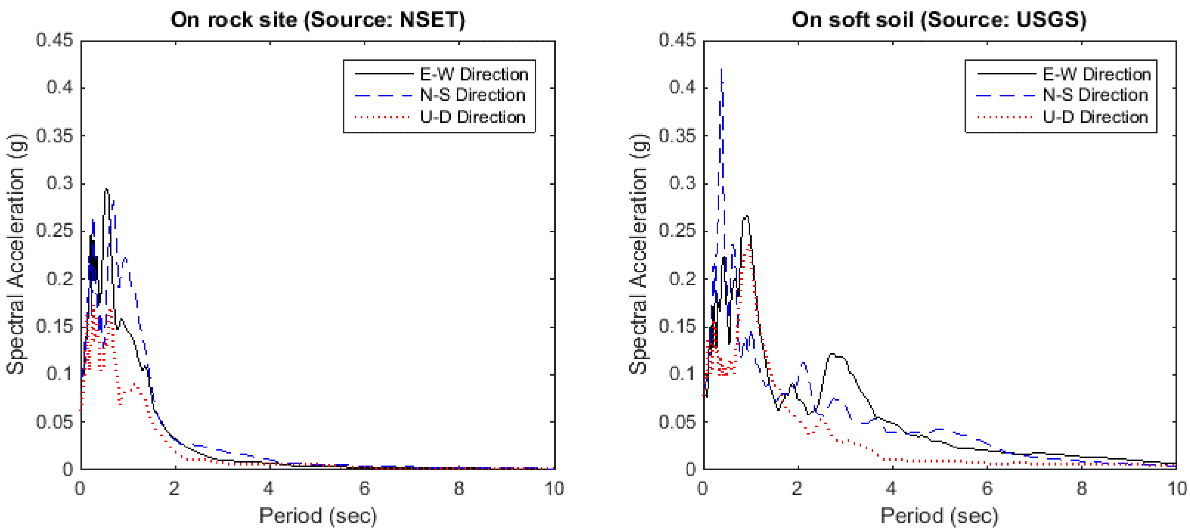


Figure 10: Comparison of spectral acceleration between soil and rock site of 12 May aftershock

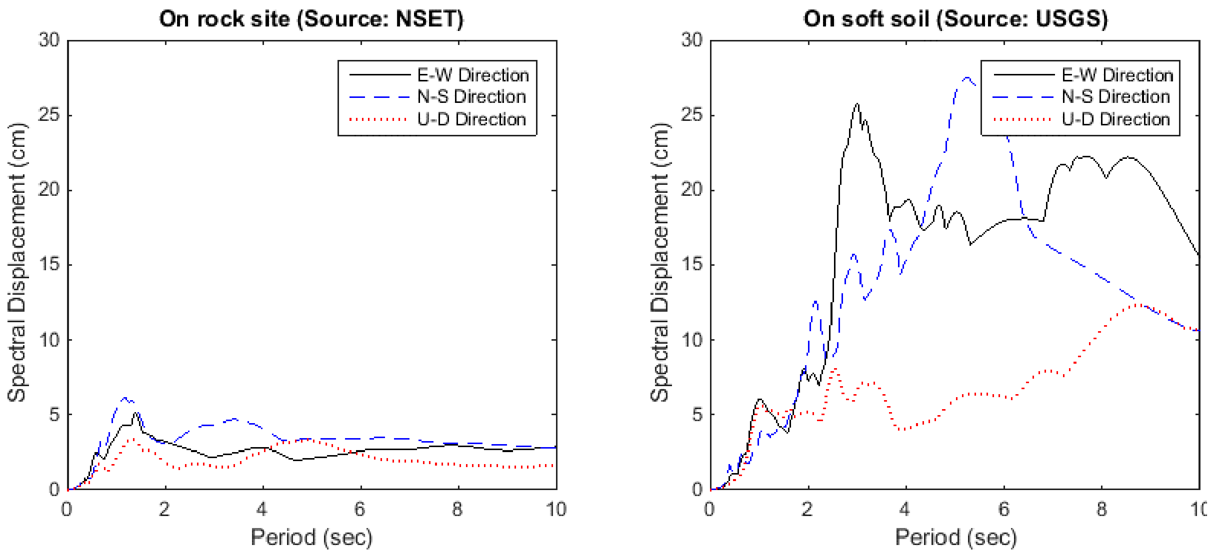


Figure 11: Comparison of spectral displacement between soft and hard soil site of 12 May aftershock

## 3 BUILDING TYPES

The total number of houses in Nepal is more than 5,400,000. The majority of them (about 44%) are made of brick and stone masonry with mud mortar (BM/SM) as shown in Figure 12. Cement mortar bonded brick and stone masonry (BC/SC) are common in urban areas and constitute about 18% of the total buildings in Nepal. In some part of the Terai region, wooden buildings are quite popular and they comprise about 25% of the total houses in Nepal.

Reinforced cement concrete with masonry infill (RCC) buildings have become popular in urban areas in recent times. The data obtained from the National Population and Housing Census (CBS 2012) shows that there are currently about 540,000 RCC buildings in Nepal and most of them are non-engineered buildings. In total, only about 2.4% of the buildings in Nepal are well designed according to the building code (Chaulagain et al. 2013). In recent years, retrofitting of schools and hospitals has been done to some extent but at the same time the rapid urbanization has led to the construction of non-engineered buildings.

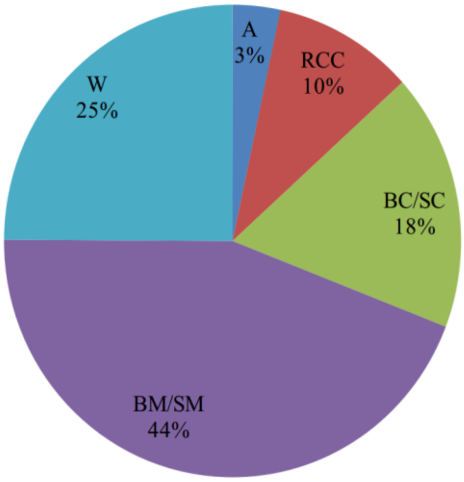


Figure 12: Building types in Nepal. (BM/SM: Mud bonded Brick/Stone Masonry, BC/SC: Cement bonded Brick/Stone Masonry, W: Wooden, RCC: Reinforced Cement Concrete with masonry infill, A: Others/Adobe) (Chaulagain et al. 2015)

# 4 DAMAGE IN BUILDINGS:

The earthquake on the 25th April 2015 was shallow, only 8.2km deep, and it caused massive damage in Nepal and its neighbouring countries. The first author visited the earthquake-affected area and carried out a reconnaissance survey one month after the major earthquake. This section presents a summary of the damage observed by the first author in different types of buildings.

## 4.1 *Damage in RCC Structures*

It is impossible to make any structure earthquake-proof but the casualties could be reduced by designing the buildings properly. The basic philosophy of earthquake resistant design is to prevent casualties from collapse of the structure under very strong earthquakes even if the structure sustains severe damage. Most of the RCC buildings were not properly designed in Nepal to withstand the earthquake force and many people lost their life due to the collapse of these structures. Some of the common problems associated with the current practice used in design and construction of RCC buildings are the soft storey effect, short column effect, detailing problems, construction/material quality, seismic pounding and non-structural damage, and these are discussed below.

### 4.1.1 *Soft and weak storey effects*

One of the major problems current buildings have is the soft storey effect particularly at (but not limited to) the first storey. This is either because the owner wanted open spaces to sell/rent to the merchants who prefer open space to sell their goods, or for parking purposes. By doing so, the stiffness and the shear strength of that floor decreases significantly and the damage concentrates at that level as shown in Figure 13. Figure 14 and Figure 15 show the soft storey effect in the ground floor. There were shops at both buildings and the stiffness of these stories were significantly low as compared to the stories with brick masonry infill(Pokharel 2015). Figure 16 shows the result of having a weak storey at the third level. The third level was constructed of unreinforced masonry whereas the storeys above and below incorporated RC elements. The weak third storey collapsed completely.

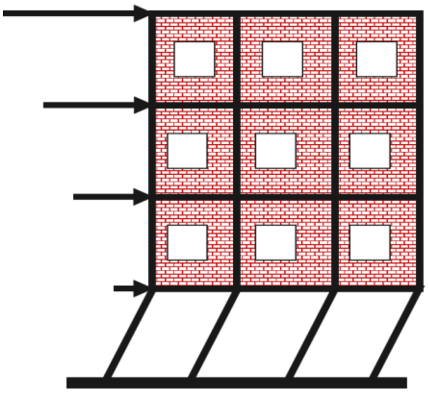

Figure 13: Soft storey effect where the stiffness of some stories are significantly less than the others. The displacement concentrates at the soft storey imposing large ductility requirements on elements at that storey.

Figure 14: Formation of plastic hinges at the end of the RCC column due to the soft storey effect in Kathmandu.

Figure 15: Soft storey effect where bottom storey of the building has suffered damage while the upper story is intact in Sindhupalchowk.

Figure 16: Third storey of the building has collapsed due to the weak storey effect in Kathmandu. The building had RCC moment resisting frames except at the third storey where there was load bearing brick masonry.

Figure 17: Soft storey failure causing tilting of building.

In some cases, some of the load bearing elements of the building failed while other members survived in the soft storey effect, resulting in the tilting of the building. Figure 17 shows some pictures of soft storey failures leading to the tilting of buildings.

### 4.1.2 *Short Column Effect*

The effect of short columns is often overlooked in the design and construction of the buildings. The short column effect can either result from partial height infill walls, the addition of an extra connection beam to support a staircase, or from sloping ground as shown in Figure 18. When there is a short column in a structure it attracts more lateral shear forces and needs to be designed accordingly. One of the observed effects of short columns due to staircase is shown in Figure 19.

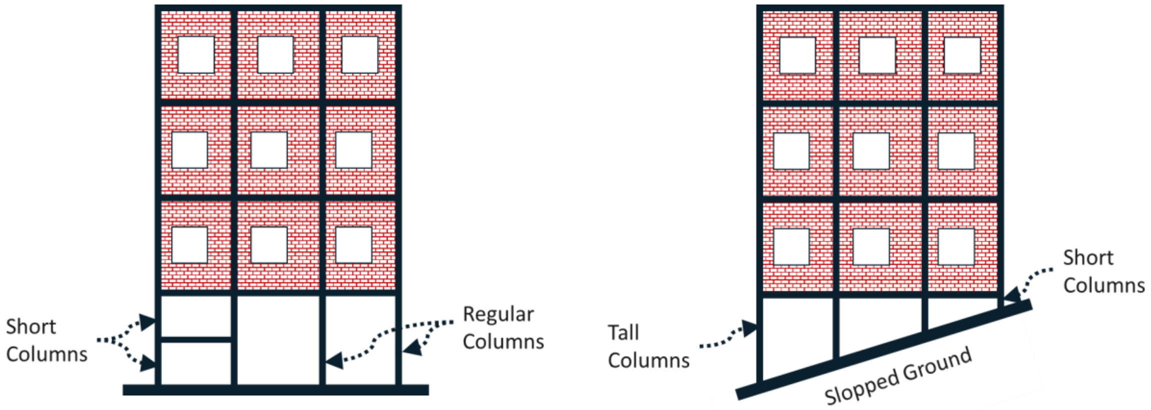


Figure 18: Conditions for formation of short columns in the RCC buildings.

Figure 19: Effect of short column in buildings.

### 4.1.3 *Design and Detailing Problems*

Another major problem with current design and construction practice in Nepal is detailing of reinforcement in reinforced concrete structures. The quantity and quality of the reinforcement used in these building is often inadequate in terms of achieving the required capacity. Strength hierarchies are often not considered, and appropriate detailing is not employed, resulting in non-ductile behaviour. Some of the common detailing problems are insufficiently large spacing of ties in columns and beams, inadequate anchorage of reinforcement, improper bending of hooks, insufficient reinforcement in the connection regions, not enough cover, and improper splicing of reinforcement. Figure 20 shows some of the detailing problems.

(a) (b) (c)

Figure 20: Problems in detailing RCC buildings. (a) Inappropriate spacing of ties, (b) bending of hooks to 90º instead of 135° and (c) insufficient shear reinforcement at critical region.

### 4.1.4 *Construction and Material Quality*

Problems with construction quality were observed at several places. This included mixing of concrete, compaction and placement of concrete, inappropriate use of formwork, and use of recycled reinforcement. Figure 21 shows some of the problems with placing and compaction of concrete in a beam column connection region. It is not common for the material and construction quality to be inspected by an independent inspector at site though there is a provision for this in the code.

(a) (b)

Figure 21: Problems with construction quality. (a) brick in beam column connection and (b) cavity in beam column connection

### 4.1.5 *Seismic Pounding*

Seismic pounding was also observed at some places. If two buildings do not have seismic joints or a sufficient gap between them and their natural period is different, they collide with each other during the earthquake which causes damage in the weaker structure. If the floor levels of the two colliding buildings are different, the damage will be more severe as the stiff floor hits the other building at the middle of the column. Figure 22 shows the effect of seismic pounding where the floor levels are at different heights.


Figure 22: Seismic pounding between two buildings with different period.

### 4.1.6 *Non-Structural Damage*

Non-structural damage was seen at many places. This includes damage to partition walls, parapet walls, false ceilings, and temporary supports. Figure 23 shows some non-structural damage in RCC buildings.

(a) (b)

Figure 23: Non-structural damage. (a) Failure of water tank support at top and (b) failure of partition wall in a high rise apartment.

## 4.2 *Damage in Unreinforced Masonry (URM) structures*

More than 60% of the buildings in Nepal are of unreinforced stone/brick masonry. Most URM buildings use mud as the binding material rather than cement mortar; the mud mortar is very poor in binding stones/bricks together. Most of the casualties in the 2015 Nepal earthquake were from the collapse of URM structures. These buildings were not designed to resist large earthquake forces and became death traps for the occupants. There are several causes of insufficient earthquake resistance including improper choice of construction material, insufficient diaphragm/connection, and lack of maintenance for old structures. Figure 24 and Figure 25 show some of the damage in URM structures.

(a) (b) (c)

Figure 24: Problems in URM construction. (a) lack of proper binding between small stones, (b) lack of proper confinement of wall and use of heavy concrete floor on weak brick masonry and (c) lack of anchorage of masonry infill walls.

(a) (b)

Figure 25: Damage in URM structures. (a) Failure of heavy metal pinnacle of a temple due to the lack of proper anchorage and (b) lack of integrity between two layers of brick wall and of connection to the roof.

## 5 DISCUSSION AND RECOMMENDATIONS:

The orthodoxy among earthquake engineers is that earthquakes do not kill people but the buildings do. The buildings need to be designed in a proper way to protect the occupants from being killed by the collapse of buildings in an earthquake. Earthquake resistant building codes exist in many countries where frequent earthquakes are expected. Nepal has also had an earthquake resistant design code since 1994 and this was enforced in Kathmandu after 2006 (UNCRD 2008). Currently the building code is mandatory only in municipalities and even in the code there are no provisions for retrofitting buildings built before the code was prepared.

The earthquake resistant code of Nepal (NBC-105 1994) is for specific types of buildings. It is also permissible to use any state-of-the-art methods in earthquake resistant design used in other parts of the world (NBC-000, 1994), and therefore engineering students in Nepal are also taught how to use international codes like the Indian codes (IS-1893 2002) and(IS-13920 1993).

Many problems explained in the previous sections are not new (see(Goldsworthy 2012)) and can be eliminated or reduced if the building code is followed in real practice. The National Seismological Centre has published a seismic hazard map for Nepal (as shown in Figure 26) which is supposed to be followed while designing buildings in Nepal. The PGA at Kathmandu valley is around 0.25g from the hazard map and the PGA from the earthquake on the 25th of April was less than that. Also, the observed spectral acceleration in Kathmandu is less than the design spectra specified in code as shown in Figure 7 for structures having fundamental periods less than 3 seconds. That means all the buildings that were designed based on the code would have been likely to be safe but in reality buildings were not constructed based on that and many suffered considerable damage.

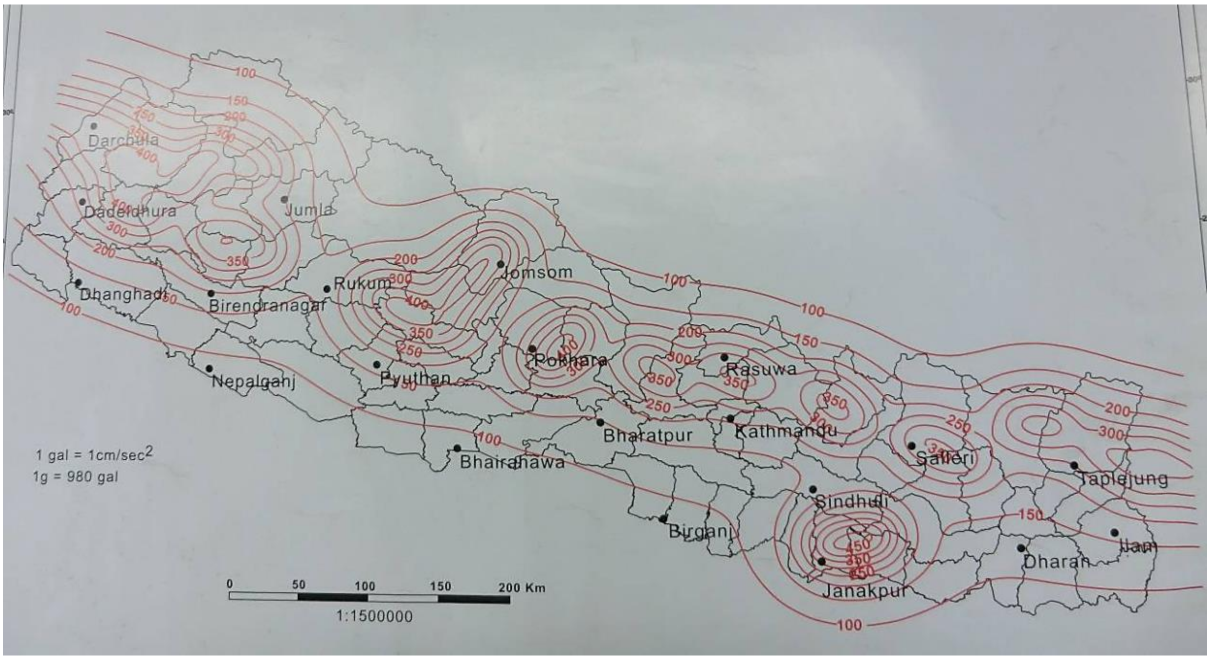


Figure 26: Seismic hazard map of Nepal showing peak ground acceleration (PGA) on bedrock in gals for 500 years return period (Wijeyewickrema et al. 2011).

Then again, buildings designed based on state-of-the-art methods will not be safe if the design is not implemented properly in the field. The first author interviewed owners, government officials, consultants and contractors during the reconnaissance visit and concluded that the implementation of design in the field is very poor. Even in Kathmandu, it is very common that the owner seeks permission to build a house with the proper design and drawings and then builds according to their convenience at the site. Thus, proper design and supervision during construction is very important for reducing damage in buildings.

For the buildings that are already constructed, a detailed assessment has to be done. Those buildings that have survived this earthquake might not survive in the next one. Retrofitting is required if their capacity (force and displacement capacity) is less than the demand based on the design codes. Many schools and hospitals had been retrofitted before the earthquake hit and most of them performed well during the earthquake. Figure 27 shows a retrofitted building in Bhaktapur which was operational after the earthquake while the other buildings in the same vicinity were heavily damaged. The retrofitting methods and techniques should use local material and human resources to make it sustainable. Nenyang Technological University (NTU) and the National Society of Earthquake Technology (NSET) have retrofitted some schools in Nepal by wrapping the beams and columns with low cost materials like wire mesh. These schools withstood the M7.8 earthquake and served as shelters for the displaced people after the earthquake (Khew 2015).

Figure 27: Retrofitted school at the middle with the green safe tag on it. Other buildings on its left and right were heavily damaged.

According to the national population and housing census (CBS 2012), 82% of the total population is in rural area where there is no mechanism for building code implementation. Although there are mandatory rules of thumb and guidelines for various structural and non-structural elements in the building up to three storeys high in Nepal [See (NBC-201 1994), (NBC-202 1994) and (NBC-203 1994)], many people are not aware of the existence of these. In the rural areas, both affected and not affected by this earthquake, it is very important to introduce earthquake resistant construction. It could be by introducing better construction materials (replacing river stones with concrete block or treated stones, using wood or reinforcement to strengthen and make the structure more ductile) and by using proper construction techniques. Simple dampers and/or isolators could also be used in some situations.

The terrain conditions are very diverse in Nepal. For example, there is a very hot plain region in the south which contrasts with the snow-capped high mountains in the north. The geology and soil conditions are also diverse. The client requirements also vary from place to place. All these parameters should be considered in designing and retrofitting the buildings in different parts of the country. The design should be done or at least checked by experienced earthquake/structural engineers. The tendency of using finite element packages without understanding the structural behaviour should be discouraged.

## 6 CONCLUSION:

A magnitude 7.8 earthquake occurred in Nepal on midday of a public holiday on the 25th of April 2015 which caused severe damage in the area. If the earthquake had occurred on a working day or at night time, the casualties would have been a lot higher. Many government offices and schools were damaged but there were no casualties in them. Many people were outside their houses for farming or other reasons which also favoured decreasing the fatalities.

Most of the buildings that were damaged by this earthquake were either brittle masonry or poorly designed/constructed RCC structures. The migration of people from rural areas to urban areas has resulted in rapid construction of housing in urban areas. Many of these houses were built by individuals based on their needs and capital without following the codes or consulting qualified engineers. The enforcement of regulations to manage housing construction has been very poor and hence the housing stock was very vulnerable.

To reduce damage due to future earthquakes, buildings should be engineered and should comply with the earthquake resistant design code. Qualified structural/earthquake engineers should be involved in designing and constructing buildings. Quality control should be taken seriously to meet the requirements. Many existing buildings also require seismic assessment. Retrofitting may be needed which, to be successful, will generally use local resources and the construction skills of local workers that have been enhanced by extra training.

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