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Performance of Buildings during Gorkha Earthquake 2015 and Recent Trends of Repair/Rehabilitation Works

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Nepal is located on a major fault-line that divides the Indian and Eurasian tectonic plates. Collisions between these plates (massive regions which created the Himalayas millions of years ago) have made the region world's most seismic active region. The main fault along which northern India underthrusts the Himalaya at a rate of approx. 20 mm/yr [1] causing the pressure accumulation along the boundary of the two plates. When the pressure exceeds capacity of the plate materials, random movement of ground triggers along the base of structure resulting inertia forces in structure which develop stresses.

On 25th April 2015 at 11.56 am (local time), Gorkha earthquake triggered with epicenter at Barpak village which is situated at about 80 km to the northwest of Kathmandu. The moment magnitude 7.8 Mw earthquake with focal depth of about 10-15 km hit Nepal. It is the biggest earthquake since 1934 eastern Bhojpur earthquake (also known as Nepal-Bihar earthquake). The earthquake followed by series of aftershocks of different magnitudes. On 12th May 2015, an aftershock of 7.3 Mw occurred at Sunakhari of Dolkha District which also caused damage in the already weakened geological fissures and structures. Nepal had experienced many devastating earthquakes with intensity greater than VIII (in Modified Mercalli Intensity (MMI) scale) in the past which were recorded in history in 1255, 1408, 1681, 1803, 1809, 1810, 1816, 1833(3 events), 1834, 1849, 1852, 1866, 1869, 1899, 1916, 1934, 1988 [2]. History shows that one large earthquake triggered in an average of 70-80 years. It is a natural phenomenon and can neither be prevented nor predicted reliably till date! However, probabilities of their occurrence and location are known. The 1934 Bihar-Nepal EQ is believed to have ruptured the MHT to the southeast of Kathmandu. It also ruptured up to the ground surface along the MFT [3]. The ruptured propagated approximately 250–300 km along the Himalaya arc [4]. However, the Gorkha earthquake and following aftershocks are blind, since they do not rupture the surface along MFT towards south of Kathmandu [5].

The Gorkha earthquake triggered ground rupture which started at the epicenter (Barpak) and propagated only towards the east direction, it continued up to Chautara of Sindhupalchowk district. Thus, huge damage is localized along rupture zone towards the east of Barpak. Due to the thick rock mass and other reasons, ground rupture could not propagated towards west of epicenter, hence very less damage in those areas. There is a big seismic gap (500 years) in the western Nepal and accumulated strain energy along the Indo-Tibetean plate boundaries is being stored in that area. This suggests large earthquake in that area in near future [6]. Following Gorkha earthquake, series of aftershocks took place towards the east of epicenter by rupturing small asperity areas in fault plane. Thus, aftershocks ground motion is dominant with higher frequencies (short time period) than mainshock ground motion. The earthquake is characterized as long period motion of about 4-5 sec (Figure 1).

There is debate regarding less damage with the size of earthquake since rupture did not penetrate up to the surface and high-frequency waves that were developed in the lower section of rupture, occurred at a depth of about 12 km. It increases the stress on the adjacent portion of the fault along MFT that remains locked, closer to Kathmandu. It is unclear whether this additional stress will eventually trigger another earthquake or if that portion of the fault will "creep"; a process that allows the two plates to move slowly past one another, dissipating stress. For such large-magnitude earthquake, high-frequency shaking in Kathmandu was actually relatively mild [1].

Despite all these the level of damage is huge from Barpak to Dolkha to the north of Kathmandu. The damage to buildings is about 80%. Nevertheless, the present earthquake and aftershocks cause huge damage in historical monuments, hospitals, schools, public, residential and other buildings as well as lifeline structures in the 14 earthquake affected districts (see Figure 2). The major

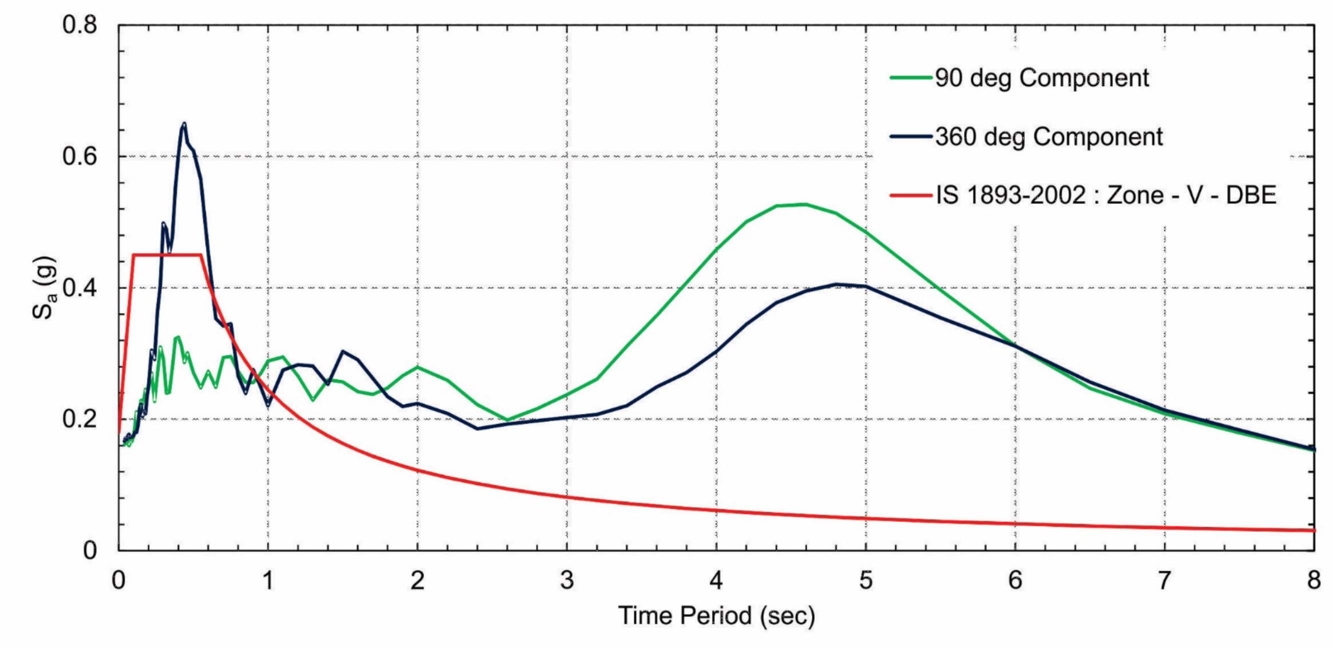

Figure 1: Response spectrum of ground motion of Gorkha earthquake 2015

shocks of April and aftershocks of May 2015 resulted human loss of about 9000. The earthquake caused huge damage to housing and human settlements. Approximately 600,000 houses were fully damaged and 280,000 houses were partially damaged severely affecting 5.4 million people in the affected districts. The effect of earthquake was severe along the rupture region, i.e., Barpak to Chautara, but its effects have been felt in remote mountain areas. The total economic loss is estimated about 7 billion USD (NPR 706 billion) [5]. The major loss is primarily due to buildings and infrastructures damage which were not planned, designed and constructed according to the expected level of shaking at a particular place that may develop due to earthquake. Dharahara used to be the symbolic icon of Nepal. Uupper floors were collapsed during 1850 ; 1934 earthquakes, but repaired after those events. There was big gap in between strength of materials used and height of the monumnet. Similarly, diameter and height of the monuments are too small to the materials used for the stability for expected level of shaking. The deterioration in the strength of materials used with time and poor maintenance seem to be the major cause of damage. Neverteless the monument need to be reconstructed, but only after proper assessment of future seismic risks and mitigating measures.

Repair, maintenance and Reconstruction should ensure sustainable and environmentally conscious process with maximum use of locally available materials and human resources as much as possible. It must consider the scientific risk assessment of the affected areas such that the future risks due to disasters can be minimized. For this public awareness and participation is must realizing the principle of Build Back Better (BBB). Here an attempt has been made to evaluate the performance of monumental, reinforced concrete (RC) buildings in the earthquake affected areas and proper repair and maintenance methods. Old unreinforced masonry buildings suffered extensive damage due to low strength of masonry via material deterioration over the years. Now there is debate among the professionals that can it be made earthquake resistant or not? The answer is yes, they can be made earthquake resistant by adopting proper anti-seismic measures.

Heritage buildings: Most of the ancient temples and monuments including Basantapur Durbar Square, Kasthamandap, Dharahara, Patan Durbar Square, Bhaktapur Durbar Square severely damaged and either partially or totally collapsed due to the Gorkha earthquake. Many of the Rana dynasty period buildings either severely damaged or collapsed where many governmental offices and other institutions were running before earthquake. These are load bearing structures with brick units bonded in mud or lime surkhi mortar. Damage grade depends on the

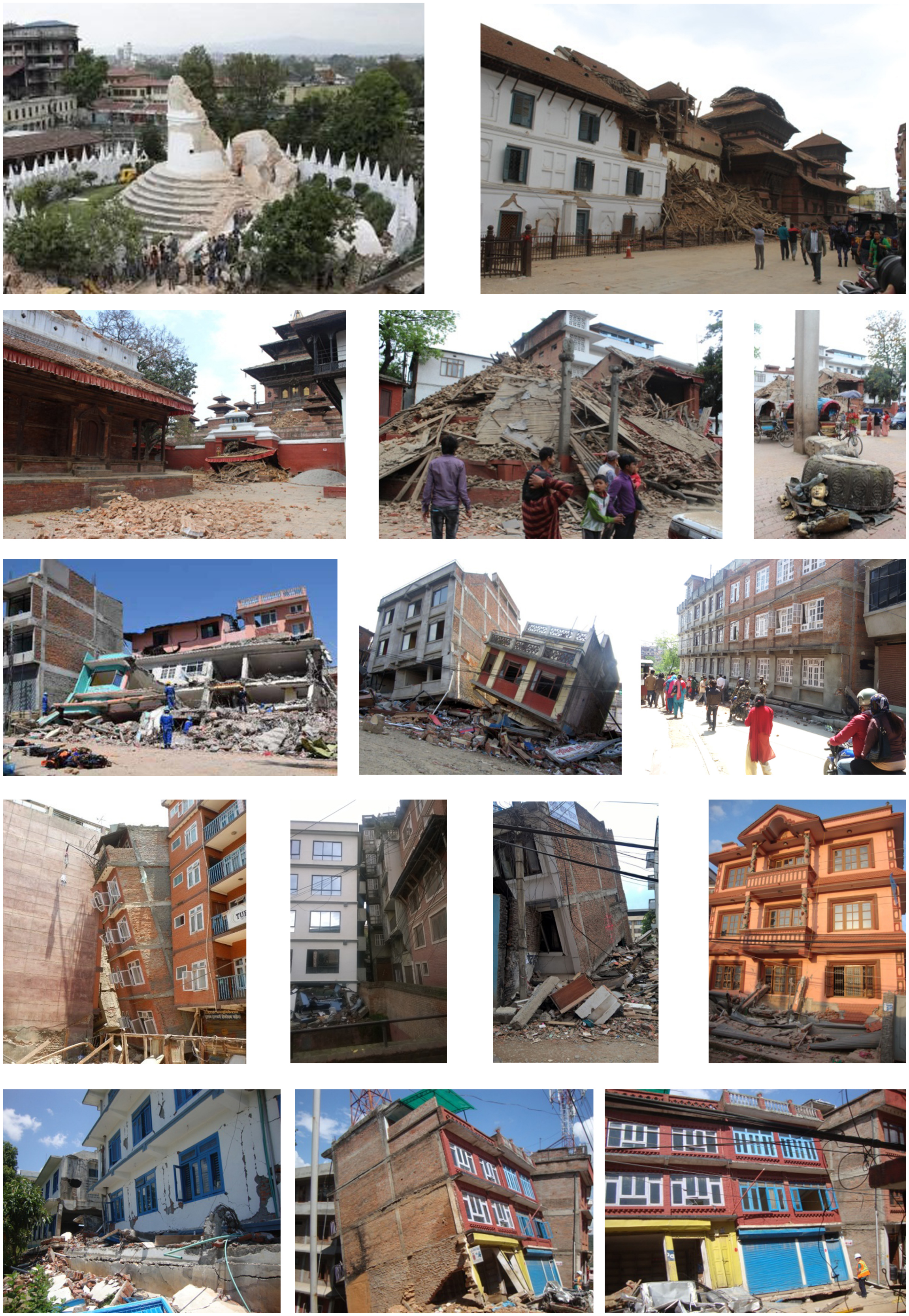

Figure 2: Dharahara, Basantapur Durbar Square, Patan Durbar Square, Sitapaila, Gongabu area, Kalanki, Sankhuchowk, Cahutara

level of shaking at a particular site. Level of shaking, is different at different places, which mostly depends on the geological conditions at a particular place. Damage to heritage monuments is site specific according to the level of shaking which they suffered. However, some tiered temples of Malla period survived 1934 as well as 2015 earthquakes. But in most cases deterioration of materials strength due to time is the main responsible factor. Properly maintained monuments (55 windows Durbar at Bhaktapur) survived. Thus, lack of proper repair, maintenance and strengthening is the main cause of damage. In case of Dharahara, there is big gap between its material type and height as well as its strength and stability for such level of shaking with the type of material used. Hospitals: All of the government hospitals started their service just after the earthquake. Most of the government as well as public hospital buildings remain serviceable after earthquake, only few buildings damaged. These buildings are RC frame structures properly designed and constructed. Some of the private hospitals, which were running in rental buildings, severely damaged and remain nonfunctional after earthquake. Damage is due to insufficient strength and in some cases due to soft storey/short column effects. In many hospitals, the level of preparedness for natural calamities seems very high and just after earthquake they started their service and worked very hard. School/College buildings: Heavy loss due to the severe damage of school buildings in Sindhupalchowk, Gorkha and Dolkha districts. Many school/college buildings in earthquake affected districts either partially or fully collapsed. Most of the buildings are of load bearing type with stone/brick masonry in mud or cement mortar. In Sindhupalchowk, Gorkha and Dolkha districts, schools with RC structures also collapsed partially or fully. In majority of cases, damage is mainly due to the absence of earthquake resistant features in these structures. However, in several cases, damage is due to the ground failure, liquefaction, basin edge effect, and ridge effects. In Sindhupalchowk district, level of shaking is high; ridge effect is also prominent, which cause the huge damage in schools and other buildings located at ridges, where some buildings with earthquake resistant features also collapsed. In Kathmandu valley, some government schools including Durbar High School, some public and private school buildings severely damaged. However, retrofitted school buildings performed very well. Earthquake occurred on Saturday at the noon, which saved many lives. University buildings: Main administrative RC blocks of Tribhuvan University are severely damaged/partially collapsed due to earthquake. There is partial damage in the old block of Botany, Physics departments, Central Library and other centers. Administrative blocks, international hostel of Institute of medicine and Maharajgung medicine campus are also severely damaged. Administrative block of Institute of Engineering and classroom/lab buildings of Pulchowk, Thapathali Campuses are also severely damaged. Main administrative blocks of Min Bhawan Campus, Bhaktapur Multiple Campus, classroom blocks of Tri-Chandra Campus, Patan Multiple Campus, Lalitpur Nursing Campus are also severely damaged. Most of the campuses in the affected districts got light to heavy damages. Other university buildings also affected due to the earthquake and most of the buildings have light to heavy damage in the affected districts. Damage to these buildings is mainly due to the deterioration of material strength, lack of repair, maintenance and strengthening works. Soil amplification is typical to laquestrine and deep clay deposits like Kathmandu valley, evidences of basin edge effect can also be seen at Naikap, Swichatar area and other places. Ridge effect is also prominent in Sindhupalchowk district. After quake people get afraid to go inside their houses even if the building suffered insignificant damage. In such instances, firstly, identify whether the damage is in structural or nonstructural members, secondly, grade the damage, thirdly, if the damage grade is I & II, then immediate occupancy is possible, if the damage grade is III further investigation is needed to identify the repair and strengthening strategy for the building. Fourthly, if the damage grade is IV detail investigation is essential to identify either repair/strengthening is possible or building is to be demolished. People often question, why to repair a building? It is very cheaper to repair a damaged building instead of demolishing it. After quake, very less damaged buildings have been restored; however, such buildings were either abandoned or demolished. Even all engineers do not understand the correct method of analysis and design of damaged structures; also builders and masons are ignorant about proper methods of restoration. People have misconception that only demolition and reconstruction is only the way to guarantee the long-term safety, which is incorrect. Also government actions seem not to promote restoration and retrofitting rather promoting demolition and reconstruction of damage buildings.

- **Repair:** For a damaged building, it is carried out to restore its pre-damage functions and architectural shape. It does not enhance the structural strength. Normally, repairing is done to correct non-structural damages as peeling of paint, plaster from wall, tiles, flooring, roofing tiles/sheets, parapet, door/windows damage, plumbing, electricity out of order etc. Only the cosmetic patches during repair may be defective and may not meet the strength requirements of the next earthquake.

- **Restoration:** Here, pre-damage strength of the structural elements is restored. First, the damage material is removed from cracked portion carefully and clean it. Cracked walls of grade II/III are normally grouted using non-expansive grout and splicing is provided across the wall either with ferrocement straps or 'C' clamps. Alternately, a) Reinforcing mesh can be added on both faces of the cracked wall using spikes or bolts and microconcrete of 1:3 (cement, coarse sand) can be applied properly. b) Injecting epoxy or neat cement slurry into the cracked portion of walls, columns, beams can be done, since epoxy is strong in tension. c) In case of delaminated or bulged portion of walls, first, remove the damaged portion, secondly, reconstruct it using same or stronger mortar by establishing proper connection of restored portion with the existing walls.

- **Restrengthening/Retrofitting:** It is carried out to increase the capacity of existing structures so that they can withstand future probable earthquakes and hence, save life and property. Thus, it aims to mitigate damage of structures during future earthquakes. Retrofitting need to be implemented in the following conditions: a) Buildings do not comply existing codes b) Seismic design forces have upgraded c) Seismic zones have upgraded d) Deterioration of structural strength due to aging of structural materials/lack of proper repair and maintenance e) Structural modification of the existing structures to change functional use affecting its strength adversely f) Increasing the floor loads in the building g) High value of the structure because of social, cultural and historical importance so that they cannot be demolished.

At present earthquake resistant design code of Nepal is in the process of revision. Buildings as well as other infrastructures need to be constructed following the National Building Code and strict supervision is needed from the concerned authority so that future earthquake vulnerability can be minimized.

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