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DAMAGE ASSESSMENT AND SEISMIC RETROFIT OF TRADITIONAL AND MODERN MIDRISE BUILDINGS IN THE AFTERMATH OF 2015 NEPAL EARTHQUAKE

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Abstract

The magnitude-7.8 earthquake on April 25, 2015 and its many aftershocks, including the magnitude-7.3 aftershock on May 12, 2015, caused massive damage to the built environment in Nepal. Near the epicenter, it had a maximum Mercalli Intensity (MMI) of IX. It is estimated that it caused over 9000 fatalities and resulted in more than 20000 injuries. The cost associated with the earthquake is estimated at roughly $US 5B which is nearly a quarter of Nepal's GDP. This event is considered the worst natural disaster in Nepal in the past eight decades. In Katmandu, which is far site from the epicenter, it is noted that the maximum peak ground acceleration was order of 0.15 g. However, the response spectrum has a pronounced peak at the high period portion of the spectrum. The large spectral acceleration at periods of 2 to 5 sec caused significant damage to midrise to tall buildings (with characteristic period in the range of ground motion amplified response.). In the aftermath of the earthquake, the authors surveyed survey the damage for two areas for importance of national agenda, tourism: the Everest and Annapurna regions. It is estimated that these regions experienced PGA of 0.1 g or less. ATC 20 (ATC 1987) methodology was used for the rapid assessment. This was followed by seismic retrofit design of modern midrise buildings damaged in the earthquake. For a number of buildings, seismic viscous dampers were selected as the retrofit option. These buildings served as the first application of passive energy dissipation in Nepal

Keywords: Nepal Earthquake, Damage assessment, Traditional building, Modern mid-rise towers, Seismic retrofit

1. 2015 Nepal Earthquake

1.1. Overview

On 25 April 2015 at 11:56 am local time, a magnitude M7.8 earthquake struck central Nepal, near the Kathmandu capital region with a population of 2.5 million. This was the largest earthquake in the area since the 1950 M8.6 earthquake in Assam, eastern India. The epicenter of this earthquake was located approximately 80 km Northwest of Kathmandu, but most of the aftershock activity was much closer. The shaking caused extensive damage to historic and commercial structures of unreinforced masonry construction. It caused over 9000 fatalities and destroyed over 600,000 structures. Economic impact is at a cost of roughly of $6B or 30% of Nepal's GDP.

1.2. Strong motion data

In Katmandu, which is built in an ancient lakebed, far from the epicenter, strong motion data from the Earthquake; see Fig. 1, was available and the peak ground acceleration was approximately 0.10-0.15 g. However, site amplification resulted in large spectral acceleration at periods of 2 to 4 sec; see **Error! Reference source not found.**. These peaks at larger periods, in-turn excited the tall buildings with fundamental periods in this period range, resulting in significant damage to these modern concrete buildings. After almost one year of political and environmental stalemate, reconstruction is just about starting.

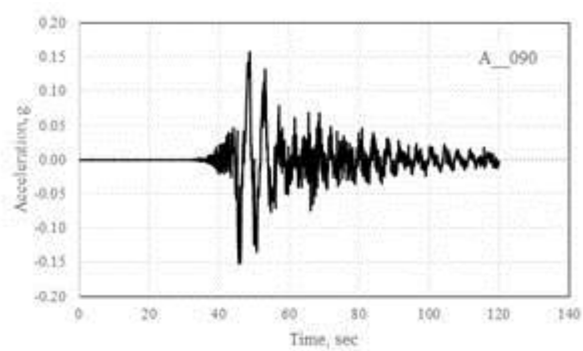

Fig. 1 Acceleration record, 90-degree component

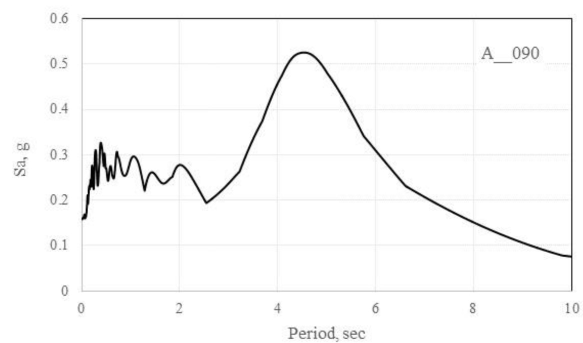

Fig. 2 5%-damped response spectrum, 90-degree component

1.3. Past seismicity

Nepal is a country known for high earthquake risk, caused by the continued northward collision of the India subcontinent against the Eurasia plate, resulting in the increasing height of the Himalaya Mountains. The underthrusting of India plate at a relative rate of 40-50 mm/yr. generates numerous earthquakes and consequently makes this area one of the most seismically hazardous regions on Earth. The surface expression of the plate boundary is marked by the foothills of the north-south trending Sulaiman Range in the west, the Indo-Burmese Arc in the east and the east-west trending Himalaya Front in the north of India. The India-Eurasia plate boundary is a diffuse boundary, which in the region near the north of India, lies within the limits of the Indus-Tsangpo (also called the Yarlung-Zangbo) Suture to the north and the Main Frontal Thrust to the south.

Examples of significant earthquakes [1] in this densely populated region, caused by reverse slip movement include; see Fig. 3; the 1934 M8.1 Bihar, the 1905 M7.5 Kangra and the 2005 M7.6 Kashmir earthquakes. The latter two resulted in the highest death tolls for Himalaya earthquakes seen to date, together killing over 100,000 people and leaving millions homeless. The largest instrumentally recorded Himalaya earthquake occurred on 15 August 1950 in Assam, eastern India. This M8.6 right lateral, strike-slip, earthquake was widely felt over a broad area of central Asia, causing extensive damage to villages in the epicentral region.

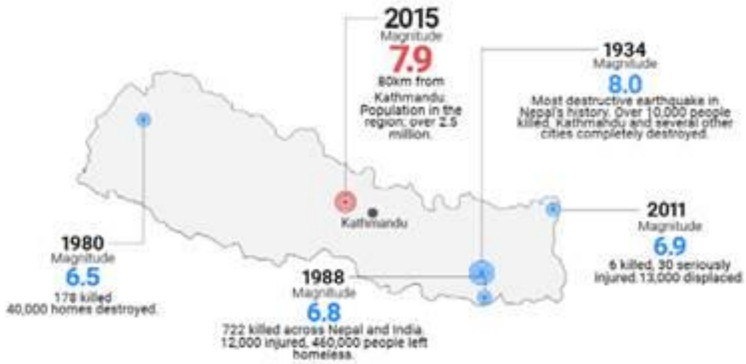

Fig. 3 Significant earthquakes affecting Nepal

The Earthquake had a maximum perceived intensity of IX in the hardest hit areas of Kathmandu; see Fig. 4. From the USGS Shakemap [1], most of the epicentral region saw MMI-VII or less shaking. It is anticipated that newer buildings constructed per modern seismic codes would only suffer minor damage in MMI-VII shaking. Older buildings and structures with known vulnerabilities (unreinforced masonry, non-ductile reinforced concrete, poorly Constructed pre-cast) buildings would experience significant damage at Intensity MMI-VII. Unfortunately, in Nepal, not unlike neighboring countries in the region, unreinforced masonry and nonductile concrete building Construction are still prevalent.

1.4. Damage summary for schools

In the past earthquakes in developing countries, school buildings have been especially vulnerable to damage from earthquakes [2]. The same was the case in Nepal; see Fig. 5. In the aftermath of the 2015 main event, data from the Department of Education [3] was analyzed by the authors. Preliminary findings are shown in **Error! Reference source not found.**. It is noted that damage to school buildings was extensive ad widespread. The number of school casualties was, fortunately, limited because the earthquake occurred on Saturday when schools were not in session.

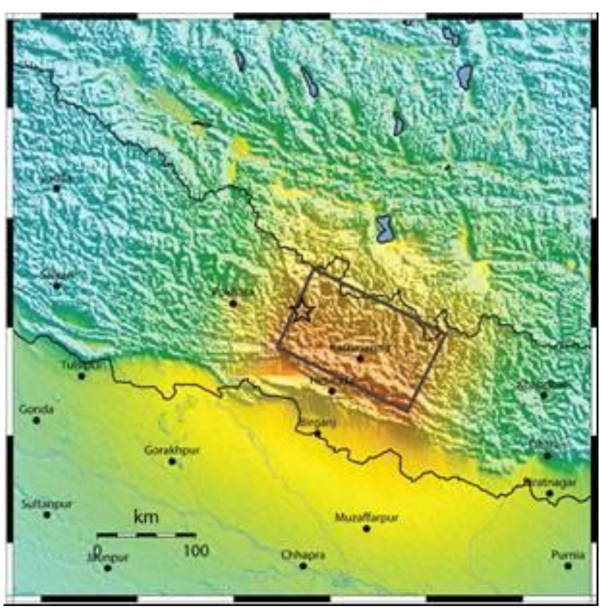

Fig. 4 USGS shakemap [1]

Fig. 5 Collapsed school building

Table 1 - Preliminary school damage statistics

District	Schools	Buildings	Classrooms	Students and Staff	Damaged schools	%
Kathmandu	299	673	3604	166000	78	26%
Lalitpur	200	602	2454	77500	149	75%
Bhaktapur	126	389	1717	36000	36	29%
Sum	625	1664	7775	279500	263	42%

2. Seismic Design Parameters

In Nepal, the seismic design spectrum is calculated from [4]:

$$C_d\,(T) = C\,(T)\,ZIK \tag{1}$$

Where:

- C (T) is the ordinate of the basic response spectrum for horizontal directions,
- T is the period, Z is the seismic zonation factor (equal to 1 for Katmandu),
- I is the importance factor (varying from 1.0 to 2.0 depending on the structure occupancy and importance),
- K is the building performance factor (varying from 1.0 to 4.0 for ductile buildings to buildings with minimal ductility).

The plateau of the spectral shape is 0.08g and the period-inverse segment starts at periods of 0.1 to 0.4 sec for various site conditions. The Nepal code spectrum for Katmandu, for the case of non-ductile ordinary building situated on soil type III (Z=1, I=1, K=1) is shown in Fig. 6.

In Nepal, the Indian Standard [5] is often used as the reference document for seismic design of buildings. This document defines the design spectrum from:

$$A_h=1/2*ZI/R*Sa \tag{2}$$

Where Sa is the ordinate of deign spectrum, the factor of 2 is used to bring the maximum considered earthquake (MCE) to Deign Earthquake (DE), Z is the zone factor for MCE (equal to 0.36 for Katmandu), I is the building importance factor, and R is the response reduction factor. The plateau of the spectrum is at 2.50, starting at 0.1 se, and the period-inverse segment starts at 0.4 to 0.67 sec depending on site condition. The Indian Standard for Katmandu, for the case of non-ductile ordinary building situated on soft soil type (Z=0.36, I=1, R=1) is shown in Fig. 6.

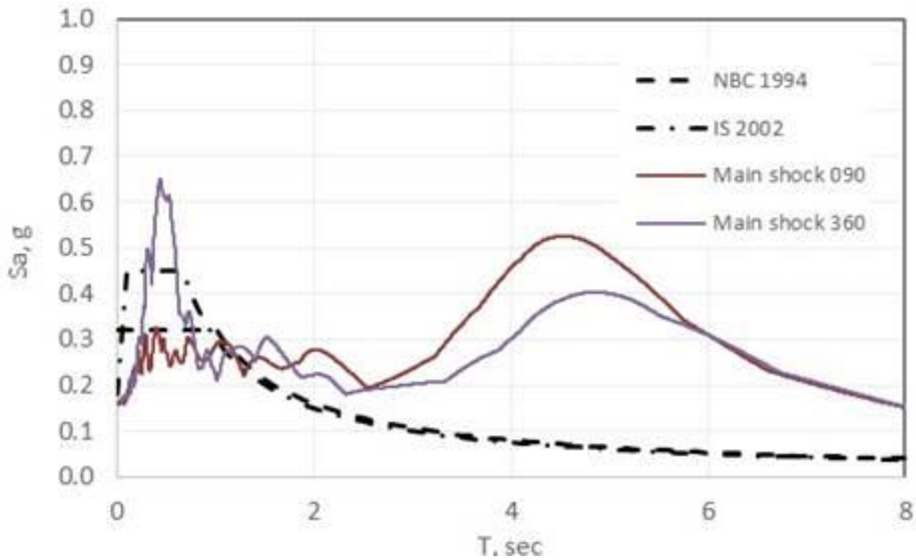

Fig. 6 Code design spectra and 2015 event spectrum

As seen in the figure, the spectral acceleration demand on buildings, in particular, for structures with periods of larger than 1 sec, is significantly larger that the spectrum used to design these structures. Accordingly, even buildings, in particular mid- and hi-rise buildings, designed per code would experience larger forces and displacements that were anticipated. The effect of such larger forces is:

- For buildings with ductile detailing, the larger demand would result in plastic hinging and damage for ductile members
- For buildings without ductility, severe damage, and collapse can be expected

3. Damage Assessment in Everest Region

3.1. Overview

The Everest region, one of the most popular tourism destinations of the country, is located in the northeast of Nepal. Following the 2015 main and aftershocks, the extent and severity of earthquake-related structural damage and geologic hazards in the region was not known.

With funding from the World Bank's International Finance Corporation (IFC) and on behalf of the government of Nepal through the Ministry of Culture, Tourism, and Civil Aviation, an assessment team was assembled and dispatched to the region to survey and record the earthquake damage along the main trekking routes with the following objectives:

- Perform quick reconnaissance of earthquake damage,
- Assess the overall trekking safety of the region's routes
- Provide recommendations on seismic risk assessment and retrofit that will inform tourism recovery and commercial readiness strategies that are currently being developed by the government, its international development partners, and Nepal's tourism industry at large.

The aim of these efforts was to promote tourism back to Nepal, which would support the overall economic recovery and return to normalcy in there. The Everest regions is located approximately 200 km and 60 km, from the epicenter of the main shock and the main after shock, respectively. This region experienced the level of shaking of MMI of V to VI.

3.2. Building types

In the Everest area, 15 main villages with approximately 710 accommodations and houses were assessed. Typical hotel construction used either wood construction of bearing wall systems. Traditional buildings used bearing walls of uncut stone with mortar and bearing walls of cut rectangular block stone with or without mortar; see Fig. 7. The older construction used mud as mortar, whereas, newer buildings used cement. Some accommodation structures in Everest utilized horizontal concrete bands spaced intermittently in the stonewall construction; see Fig. 8. Typical roof construction used metal corrugated roof panels placed on top of wood framing. In a few, flagstone roof tiles, approximately 25 mm thick, were used on top of wood framing. Typical floor construction used mud placed over flat wood boards over wood beam framing. In some cases, there was no mud used and wood flooring was placed over wood framing. Typical foundations, according to local residents, were approximately one m deep below walls and were constructed using the same material as the wall itself, typically stone with mud, or cement mortar.

Fig. 7 Traditional bearing wall building

Fig. 8 Building with concrete band

Typical accommodation construction types included uncut stone with mortar and cut rectangular block stone with or without cement mortar. Older construction typically used mud as mortar and it was found that newer construction for the most part used cement. Newer construction that used cement as mortar typically performed well in the earthquake, while construction types with mud as mortar and uncut stone sustained substantial damage and collapse in the earthquakes.

Although it is known that many of the buildings have multi-occupancy categories serving as residences, tourist accommodations and teahouses, a distinction can be drawn between typical residential housing construction used by village locals and typical accommodation structures. The typical residential buildings used by village locals are typically made from only locally available materials such as rock and mud, which performed poorly as noted above. We found that overall the main accommodation structures are typically of better construction and included materials such as cement and cut rock or lightweight wood studs, which perform better in earthquakes.

3.3. Observed damage

The level of damage in traditional construction was highly depended on the construction practice. The buildings with stone and mortar generally performed well. Although cracks were noticed in many of these buildings, these cracks did not pose a safety hazard. By contrast, in older buildings where either no mortar was used or when mud was used as mortar, there was significant damage. For these buildings, as shown in **Error! Reference source not found.**, the out-of-plane failure of walls was the most common mode of failure, where stonewalls fell over or stones fell out, generally at the top of the walls. Since these bearing walls carry both seismic and gravity loading, their out-of-plane failure can compromise the gravity load path and can result in collapse of roofs and floors. For the surveyed buildings, a secondary wood beam supporting the roof was observed in many of the buildings. This member supported the roof after the failure of walls and prevented collapse of the roof. Visual observations also showed that, of the traditional buildings that experienced damage, the mud mortar appeared to be more brittle than the mud in other buildings. Accommodation structure built with cut rock, cement, and ring beams that performed well; see **Error! Reference source not found.**.

Wood structures were mostly small extensions of the stone hotels and were typically single-story units. Many of the wood structures were open with long bays of windows interrupted by wood posts and lacked a defined lateral load-resisting system. Despite this major shortcoming, no damage was observed for these buildings.

Fig. 9 Out-of-plane failure of bearing wall building

Fig. 10 Undamaged accommodation building

3.4. Damage assessment

The structural assessment of the buildings was conducted in accordance with the internationally recognized ATC-20 [6] and the national guidelines for post-earthquake damage assessment specified by the Department of Urban Development and Building Construction (DUDBC) of the Government of Nepal. Out of approximately 710 surveyed buildings, earthquake damage of structural concern was observed in 120 buildings (17%); 83 percent of buildings were given a green tag per ATC-20 and DUDBC guidelines. It was found that most of the damaged buildings were repairable.

4. Seismic Evaluation and Retrofit of mid-rise Buildings in Katmandu

4.1. Overview

As mentioned previously, the soft soil underlying the Katmandu region produced large spectral accelerations in the 1-4 sec period range and excited mid-rise buildings. Many of these buildings are of newer construction vintage, had ductile detailing, and as such did not experience collapse. However, damage to these tower buildings was widespread; see **Error! Reference source not found.**. Most of the mid-rise buildings used reinforced concrete moment framing as the lateral force resisting system. In addition, unreinforced infill walls were used for these buildings. The damage to the infill walls was extensive; see Fig. 12, which caused the tenants to move temporarily out of these units. It is noted that these are high-end condominium units.

Fig. 11 Exterior cracking, residential tower

Fig. 12 Interior diagonal cracking of infill walls

4.2. Seismic retrofit of mid-rise towers with seismic energy dissipation.

The application of seismic dampers to an existing building was demonstrated after damage assessment of a residential tower was completed. The 10-story 32-m tall tower is approximately square in plan measuring 18 m on side; see Fig. 13. This tower was constructed using reinforced concrete moment frame system with masonry infill. Typical columns were 600x600 mm to 800x800 mm square and rectangular beams measured 300x600 mm. The mathematical model of the building is presented in Fig. 14. In this model, the diagonal viscous dampers are also shown. The building seismic weight is approximately 47 MN.

Fig. 13 Photograph of residential tower

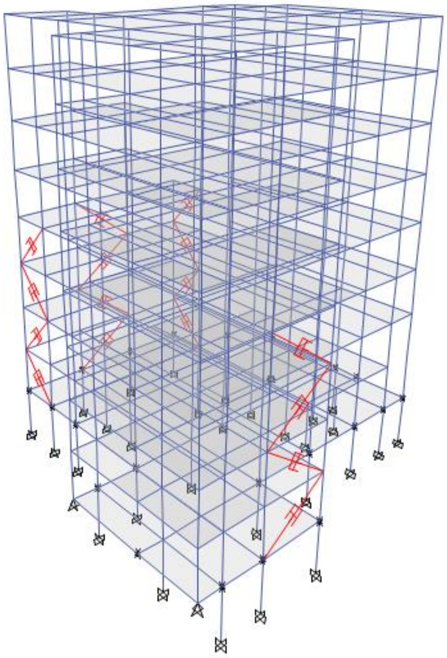

Fig. 14 Mathematical model of the tower

The building in its existing condition and with the damaged infill masonry bays seismically retrofitted with viscous dampers was analysis. Two sets of nonlinear response history analyses were conducted. In the first set, the recorded accelerations from the 2015 earthquake (see Fig. 1 for the trace of one of the components) were used as input. In the second set, spectrum-matching algorithm was used to synthesize acceleration records whose spectra closely matched the unreduced target spectrum of Indian Standard (see Fig. 6).

Fig. 15 and Fig. 16 present the computed drift ratios for the 2015 event and code-spectrum synthesized record analysis. It is noted that the addition of viscous dampers have significantly reduced the drift ratios and demando n the drift-sensitive reinforced concrete movement frame beams and columns.

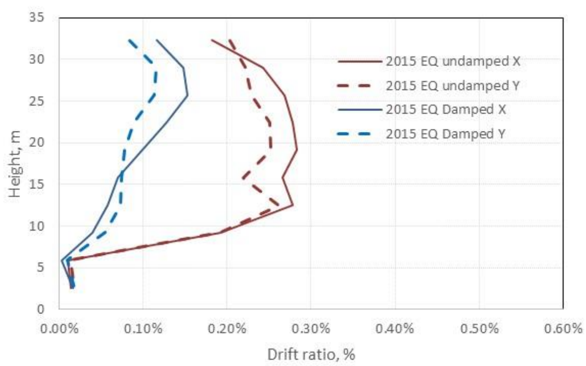

Fig. 15 2015-earthquake analysis

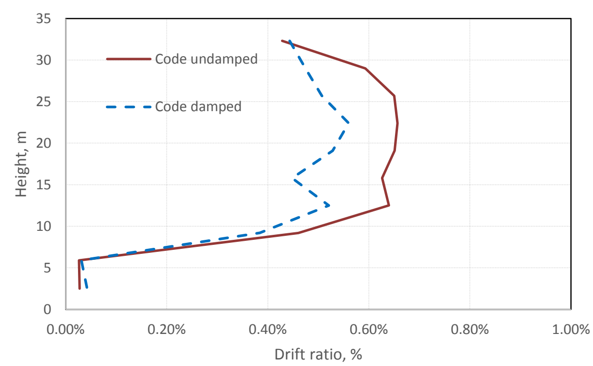

Fig. 16 Code-spectrum matched analysis

4.3. Seismic design of new hotel building with dampers

The new 70-m tall hotel building has 15 stories and 3 basement levels; see Fig. 14. The dual system of reinforced concrete moment frame exterior shear walls comprises the lateral load resisting system. The structure was designed per IS 2002 [5]. Following the 2015 Earthquake, it was decided to add the additional requirement of limiting the drift ratios to approximately 1.5% for a seismic event comparable to that earthquake. As shown in Fig. 18, the building nearly met this criterion in the transverse direction. However, in the longitudinal direction, at the lower three levels, drift ratios exceeded this limit. To reduce the drift ratios, viscous dampers were added at these levels along the longitudinal direction. As shown in the figure, in the new configuration, drift ratios were limited to approximately 1.5%.

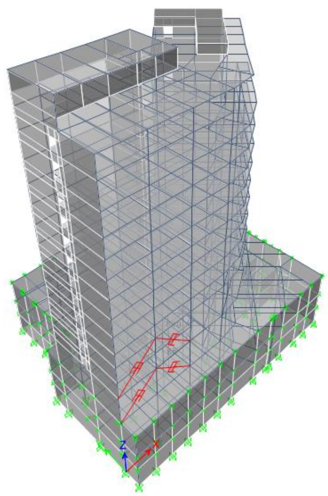

Fig. 17 -2015-earthquake analysis

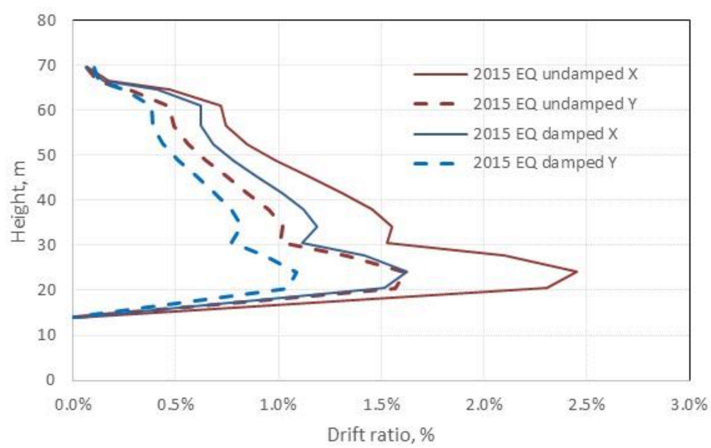

Fig. 18 2015-earthquake analysis

5. Conclusions

The 2015 Nepal Earthquake resulted in significant casualties, collapsed building, and economic losses. Although the consequences were extensive, this was not unexpected, given the seismicity of the area.

- The seismic demand produced by the earthquake, exceeded the design-level forces prescribed in the building codes for this area.
- School buildings were hard hit, similar to recent earthquakes elsewhere.
- Many older URM and nonductile reinforced concrete buildings collapsed
- The traditional buildings only sustained minor damage when concrete band and good mortar was used.
- The earthquake had spectral peaks at large periods that caused damage to mid-rise buildings
- Both existing and new construction have been selected for application of seismic dampers. Analysis has shown that the use of dampers resulted in significant reduction on demand to reinforced concrete frame members.

6. Acknowledgements

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7. References

[1] USGS, (2015), United States geological Survey

[2] Miyamoto, H.K., Gilani, A.S.J., and Wong K. (2011), Massive Damage Assessment Program and Repair and Reconstruction Strategy in the Aftermath of the 2010 Haiti *Earthquake, Earthquake Spectra*, Volume 27, No. S1, pages S219–S237, VC 2011, Earthquake Engineering Research Institute, Oakland, CA, US.

[3] DoE (2015), Department of Education, government of Nepal, *Personal communications*

[4] NBC 105 (1994), Government of Nepal Ministry of Physical Planning and Works, Department of Urban Development and Building Construction, *Nepal National Building Code, Seismic Design of Buildings In Nepal*, Babar Mahal, Kathmandu, Nepal.

[5] Indian Standard (2002), Bureau of Indian Standards, *Criteria for Earthquake Resistant Design of Structures, Part 1 general Provisions and Buildings*, New Delhi, India.

[6] Applied Technology Council (ATC), 2005. ATC-20: *Set Procedures For Post-Earthquake Safety Evaluation Of Buildings & Addendum*, Applied Technology Council, Redwood City, CA.