EARTHQUAKE HAZARD CENTRE
NEWSLETTER

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Contents

Editorial: January 2013

First, we wish our readers a Happy New Year. May 2013 be enjoyable and fruitful for you.

Almost two years since most of the unreinforced masonry buildings in the CBD of Christchurch were destroyed by an earthquake, after-shocks are continuing. While the shocks from tectonic movement are now small and far less frequent, shocks of a different kind are affecting the whole of New Zealand.

Right through the country there is a realisation that many of the old brick buildings in every town and city, and even concrete buildings built prior to 1975, may one day suffer the same damage as those in Christchurch. For some communities it is truly shocking to discover that many of their buildings are earthquake prone, in that they are less than 34% of the strength of an equivalent new building. This hidden shock is affecting all sectors in society as their buildings are assessed by structural engineers. Some school buildings below the 34% standard are being vacated, police stations are relocated into safer premises and tenants of brick buildings, feeling anxious occupying an old building, are moving into safer buildings where these are available.

Many buildings are currently being seismically retrofitted. Structural engineers are in enormous demand as this seismic shift affects building owners. The Virtual Site Visit of this issue takes us to the site of a concrete frame building being retrofitted.

So what has happened is that shock waves from one localized quake, in Christchurch, are now affecting the whole country. Local councils are, by law, obliged to improve the safety of their communities' buildings, so they are orchestrating the assessment of buildings perceived to be at-risk and building owners are then left to decide whether to retrofit or demolish.

This ripple or spreading effect is likely to happen in other countries as well. Next time a city in your country is 'hit' you can expect that the seismic safety of buildings very distant from that event to be queried. Knowing that one day the buildings we are designing now will probably be subject either to an earthquake or at least careful scrutiny are powerful reasons for us to design to the highest standards. If an earthquake doesn't by brute and dynamic force show up a building's inherent weaknesses, then structural engineers in the future will.

So we need to apply best practice to all aspects of the seismic design and construction of our buildings. We need to start with a well-configured building – no short columns, soft-storeys and significant torsional eccentricity. If possible we will suggest reinforced concrete shear walls to resist lateral forces, aware of their good track record. We will also need to stop pretending that infill masonry walls don't affect how open frames perform. Infill walls have enormous, and usually undesirable effects on frames during a quake. Then, finally in this short-list of what to do for better seismic performance, we need to design ductile buildings – buildings that when subjected to shaking more intense than the code level quake, won't collapse.

Virtual Site Visit No. 31. Retrofitting a multi storey building

In this issue we visit an existing building undergoing seismic retrofit. The building consists of three separate buildings, six storeys high. Two were built in 1930 and the other, shown here, in 1960. They are being tied together under every floor diaphragm so that the three buildings will act as one.

As can be seen in Figs. 1 and 3, the exterior frame consists of weak columns and strong beams. Because of its age which suggests non-ductile detailing, the building can be assumed to be both weak and brittle. In a moderate earthquake the exterior columns would probably fail in shear and be unable to support the weight of the building.

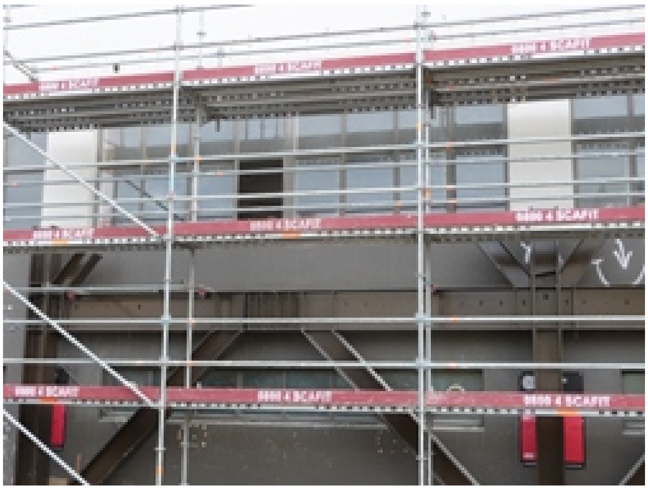

Fig. 1 The eccentrically braced frame with its beam at first floor.

Fig. 2 Reinforcing tied into the existing building that will become the means of transferring seismic forces from the old into the new structure.

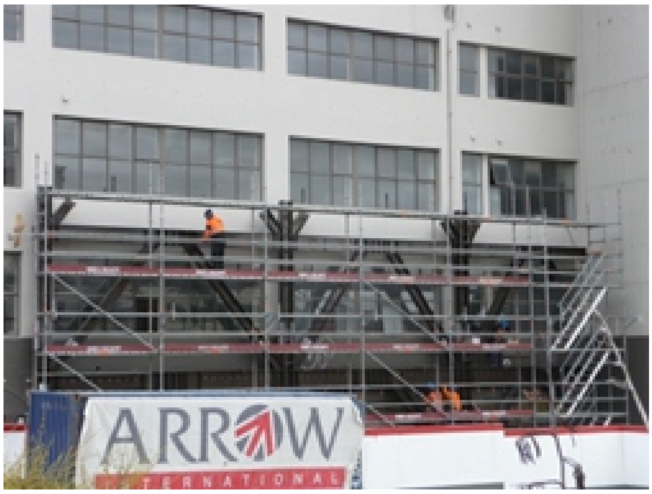

Fig. 3 The eccentric braced frame at the second storey level is being bolted to the steel framing beneath.

To remedy these deficiencies new structural systems are being introduced into the building. On the northern face, the most effective solution has been to construct a new sprayed reinforced concrete wall. On the southern elevation, shown here, a three-bay eccentrically braced frame is being constructed on new cast-in-place piled foundations. Fig. 1 shows the top portion of the ground floor steel framing of the eccentrically braced frame. To provide a strong connection in order to tie the new frames to the existing building, reinforcing bars are grouted into the existing building to create a reinforced concrete corbel which is poured after the steel beam is in position and bolts along its length have been placed. This method satisfactorilly overcomes problems of construction tolerances. Note that the plaster on the building surface has been removed and the concrete roughened so as the new concrete will bond strongly with the existing concrete. As the building is equally seismically vulnerable in the other direction, another two eccentrically braced frames, each of two bays will be constructed within the building. Conveniently, the building contains a full-height internal atrium. After new foundations are constructed, the new frames will be be craned in over the roof and placed along two sides of the atrium and very strongly connected to the floor diaphragms.

LEARNING FROM EARTHQUAKES

Summary of "the EERI Special Earthquake Report - December 2012 - The Mw 6.4 and Mw 6.3 Iran Earthquakes of August 11, 2012", by members of the Iranian Earthquake Engineering Association (IEEA): Mohsen Ghafory- Ashtiany, Mehran S. Razzaghi, Mohammad Davoodi, Afshin Kalantari, Mohammad Tatar, Farokh Parsizadeh and edited by Sarah Nathe.

Introduction

On August 11th 2012 at 04:53 p.m. (local time), a Mw 6.4 (NEIC) earthquake struck near the cities of Aharand Varzaghan in the East Azerbaijan province in northwest Iran. This quake was followed by another Mw 6.3 earthquake 11 minutes later at 05:04 p.m. The second quake was located just below the first at a depth of around 16 km. The earthquakes destroyed more than 20 villages and damaged the cities of Varzaghan, Ahar, and Heriss. The earthquakes killed 327 people, caused more than 3,000 injuries, and left more than 30,000 homeless.

Many adobe buildings in villages collapsed and several masonry and framed buildings were damaged. Roads were damaged by surface faulting and geotechnical instabilities; some bridges were damaged, but remained serviceable. Many essential facilities such as hospitals were damaged and some industrial plants were closed and suffered significant economic losses.

Performance of Residential Buildings

Most of the collapsed and damaged houses in the affected villages were adobe and unreinforced masonry buildings. The main failure modes were collapse of heavy roofs, in-

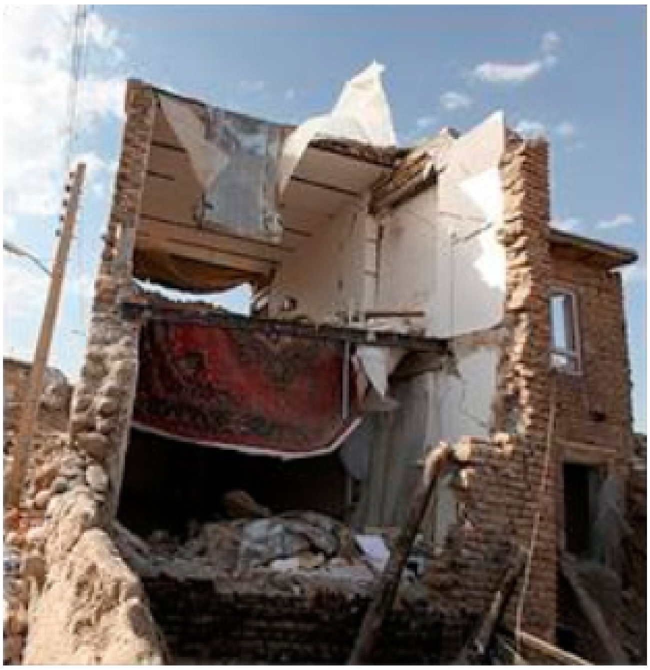

Fig. 4 Failure of heavy steel jack-arch and concrete roofs, and walls of unreinforced masonry buildings (photos: Mehr News Agency; Bastami).

Fig. 5 Buildings that met minimum code requirements performed well (photos: Mehr News Agency; Kalantari; Bastami).

plane failure of walls, and out-of plane failure of walls as shown (Figure 4). In general, performance of brick masonry buildings was better than that of adobe ones. Both framed (steel and RC) structures and brick masonry buildings are found in urban areas. No structural damage, and little non-structural damage, was seen in residential buildings in Herris. However, residential buildings of different types were damaged in both Ahar and Varzaghan. Infill walls in some buildings cracked in the northern parts of Tabriz. Most buildings that met minimum code requirements survived the earthquake, as shown in Figure 5.

Performance of Essential Facilities

Hospitals: The performance of hospitals was unacceptable. The main Heriss Hospital, with a RC moment-resisting frame, had some structural damage due to plastic hinges and the failure of many columns near the beam-to-column joint (Figure 6). All of the observed plastic hinges were located in the columns of the first floor. Some of the columns had shear cracks next to the openings of the infill walls. In addition to the aforementioned failures, diagonal cracks were observed in some of the beams next to the column joint. The main reasons for poor performance were slipshod construction methods, low-quality concrete, and insufficient bondage of cement paste and the aggregates. Figure 7 shows photos of non-structural damage to the Herris Hospital: diagonal cracking and out-of-plane failure of infill walls, and failure of facades and false ceilings. The hospital was not operable after the earthquake. The Bagher-Al-Oloom Hospital in Ahar also had extensive non-structural damage and was put out of commission after the earthquake. In-plane failure of infill walls, failure of false ceilings, and overturning of medical equipment were the major problems.

Universities: There was no observable structural damage in universities and dormitory buildings in Ahar, Varzaghan, or Herris. Several non-structural failures were seen in educational and dormitory buildings at Varzaghan Islamic Azad University (IAU), a four-story steel-frame structure. Failure of infill and partition walls, damage to false ceilings, and overturning of unstable equipment and shelves were the major non-structural failure modes. There were no deaths or injuries reported in the universities.

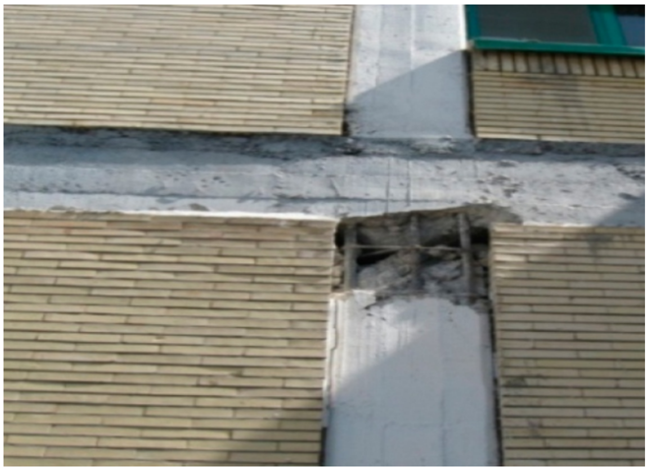

Fig. 6 Herris Hospital structural damage: plastic hinges in beam column joints (center) and diagonal crack in a column (bottom).

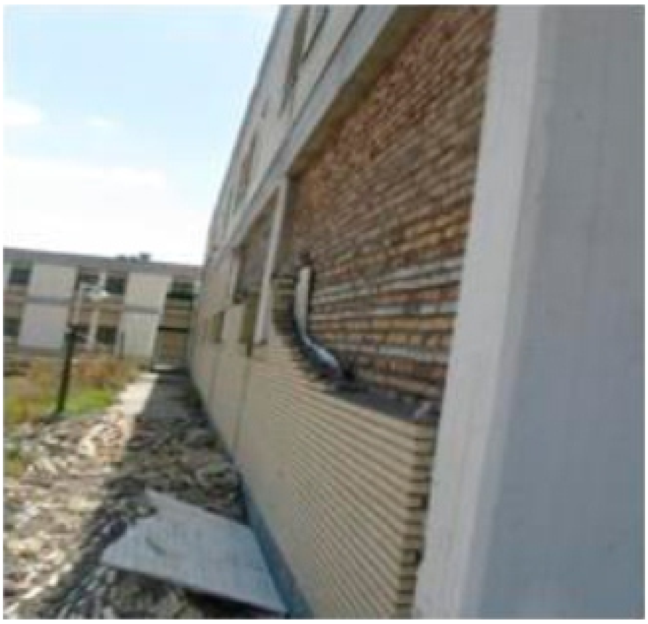

Fig. 7 Some of the nonstructural damage to Herris Hospital.

Summary of "Implementing School retrofitting Program in Nepal: Experiences and Lessons Learnt",

by J. S. Vishokarma, R. H. Dahal, S. P Acharya, R. Guragain & A. M. Dixit, from the Proceedings of the 15th World Conference on Earthquake Engineering, Lisbon, 2012.

Summary

There are about 82,000 buildings belonging to more than 33,000 schools in Nepal, out of which about 60,000 buildings require seismic improvement. Retrofitting of school buildings was first introduced by National Society for Earthquake Technology- Nepal (NSET) in 1997. There has been a greater realization by National and international community in the need for improving seismic safety of schools. The Department of Education (DOE) along the line of Flagship program of NRRC has developed a 5 year comprehensive plan for retrofitting of 900 school buildings of the Kathmandu Valley in 5 years and 60,000 buildings of the whole country in next 15 years. DOE has implemented retrofitting of 15 school buildings in 2010/2011 and another 50 buildings are being retrofitted through the support from NSET and ADB. This paper highlights the experiences, challenges faced and lessons learnt with replicable models in implementing school retrofitting program in Nepal.

Introduction

Government of Nepal recognized the need of school vulnerability reduction and institutionalized School Earthquake Safety Program (SESP) in 2010 and implemented a pilot program in 15 schools with the technical support from ADB through NSET. ADB and NSET developed concept paper for the vulnerability reduction of the schools of the Kathmandu Valley in 2010. Based on the concept paper, ADB and NSET again carried out snapshot study of the schools of the valley and recommend detail plans of action to reduce seismic vulnerability of all the schools of the Valley. Incorporating the lessons and experiences of piloting the program in 65 schools of the Valley, the DOE has developed a 5-6 years plan to strengthen existing 900 school buildings of the valley and calculated approximate cost of US$ 30 million. The DOE through the support from the ADB is retrofitting 260 school buildings by 2014, for which the funding resources have already been identified.

Retrofitting Program

Recognizing the outcome of the SESP implemented in the past, the DOE has come up with a same concept of SESP. The components of the program included are based on the approach and vision of making all community of Nepal safer against earthquake which include:

- Selection of 15 school buildings from the three districts of the Valley (5 from each)
- Detailed seismic vulnerable assessment of selected buildings and designing for possible vulnerability reduction methods
- Implementation of retrofitting works
- Training of DOE engineers on detailed assessment, retrofit design and retrofitting techniques of different types of buildings
- Training of local masons on seismic retrofitting and earthquake-safe construction techniques
- Training of teachers and orientation of students on earthquake preparedness and response in schools
- Preparation of earthquake preparedness and response plans and conduct drills
- Awareness program to the parents and the school management committee
- Development of training curricula and guidelines to different target groups.

Technical Details

Following is the details of the selected school buildings for retrofitting.

Building types

All the buildings selected were of load-bearing masonry types with some of them of RCC slab and some of flexible roofs. The buildings were up to 3 storeys. Almost all the buildings were typically single bay with a passage on a cantilever projection. Most of the buildings were elongated in shape and do not comply with codes. The age of the buildings varies from 10 to 30 years. These buildings were constructed by the local people with support from DOE, some international organizations, community contribution and through charities.

The majority of the school buildings were of mixed type i.e. one floor with brick in mud and another with brick in cement, one floor RCC and the other floor or roof of flexible material. Few buildings were built with the cement mortar.

Vulnerability Assessment and design for retrofitting

Seismic vulnerability assessment and design of the buildings was carried out through the following process

Qualitative assessment

The following processes weas involved in qualitative assessment:

- Visual inspection, data collection, verification of designs and drawings
- Determine region of seismicity
- Determine level of performance
- Determine fragility
- Identify vulnerability factors
- Determine probable performance at different intensities

Quantitative assessment

The following process were involved in quantitative assessment.

- Field observation by visual observation
- Field verification with non-destructive and intrusive tests to identify shear strength of walls
- Determination of mechanical properties of the building
- Analysis and interpretation of results

Retrofit design

- Setting performance objectives
- Selection of appropriate retrofitting options
- Design of retrofitting elements such as jacket, splints, bands.

Vulnerability assessment and retrofitting design was conducted by a specialized team from NSET. This opportunity was also utilized by the DOE engineers in learning the process through practical work as well as formal training. RCC jacketing and splints and bands were proposed as options of retrofitting.

Implementation of Seismic Retrofitting

The retrofitting work was implemented through the community under the supervision of DEO engineers with the technical guidance from NSET. Entire construction management including materials, human resources and site facilities was managed by the school, school management committee and the local people.

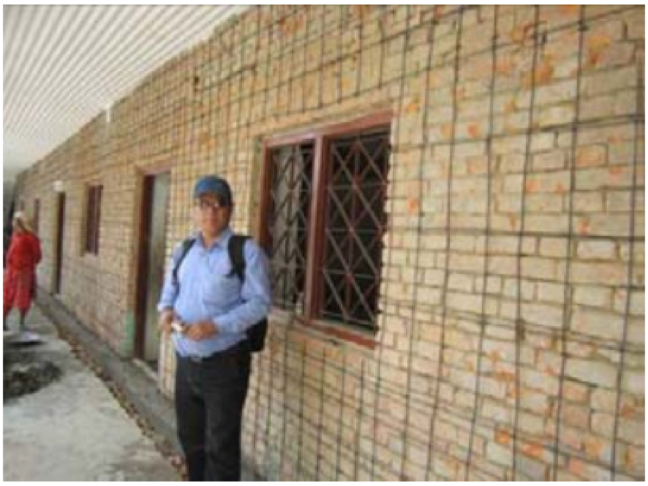

Fig. 8 RCC Jacketing of exterior walls.

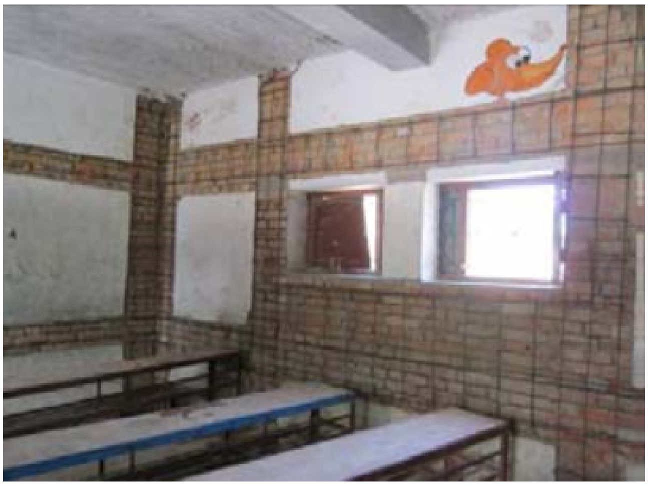

Fig. 9 RCC splints and bands on interior wallslevel.

NSET and DEO jointly supported the schools in all technical and management aspects for ensuring quality of the work. Special attention was given on the selection of quality materials and adequately skilled workers. Before starting actual works, orientation to the engineers, technicians and the masons was conducted. This helped to replicate the designs in actual implementation.

Different training and awareness programs were inbuilt in the program. Teachers of all the schools were trained and students were oriented. Earthquake drill was conducted in all the schools. The teachers and students cooperated well in making their school safer from earthquake.

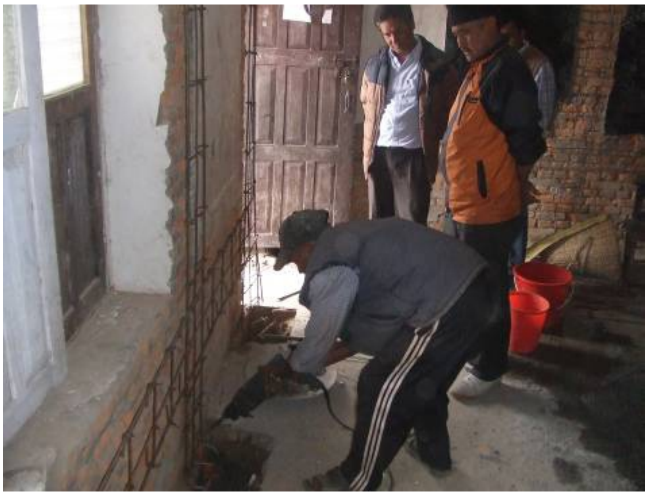

Fig. 10 Opportunity for students to learn.

Fig. 11 Opportunity for all to learn.

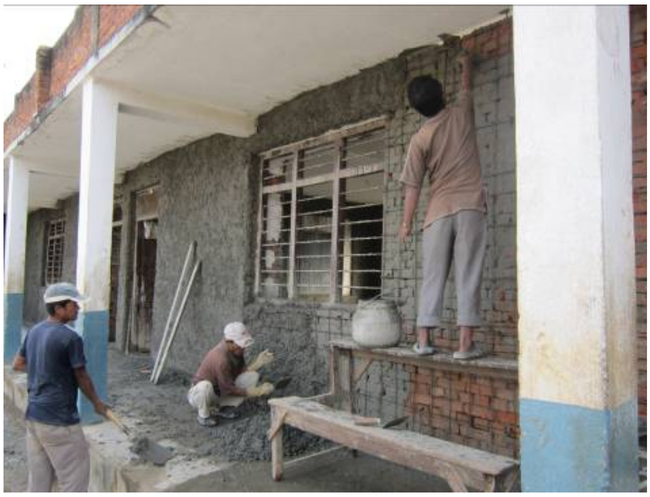

Fig. 12 Micro-concreting grouting.

Fig. 13 Surface finish.

The Figure 8 above shows reinforcement placed for jacketing of outer surface of the building and the Figure 9 shows the reinforcement details of the vertical splints and horizontal bands in the inner walls of the buildings. These reinforcing bars are anchored properly with the wall through drilling holes and inserting galvanized steel bars throughout the wall cross-section. The size and spacing of the reinforcing bars differs in each buildings based on the design. These elements are supposed to hold the masonry unit as well as entire component of the building together to have box effect during an earthquake and minimize the extent of damage.

In the Figure 10 above, the students of the school were taken to the retrofitting site after orientation on earthquake safety to observe what is being done to strengthen their school and asking the masons will their building be really safer. Similarly in the Figure 11, the local people are observing the placing of reinforcing bars and discussing with the working masons and asking them either they can retrofit their buildings if required. Retrofitting of school was also utilized as an awareness building tool in the locality.

Figure 12 above shows the masons grouting the reinforced wall with 50 mm thick micro-concrete of grade M20. Before applying micro-concrete, one coat of neat cement slurry was sprayed to ensure proper bonding of the concrete with the brick wall. Figure 13 above shows the final surface finish after 2 layers of microconcrete of 25 mm thick each was applied before plastering the surface. The final surface is ready for painting.

Lessons Learned

The following lessons were learned from the implementation of SESP and retrofitting of 15 school buildings in the Kathmandu Valley.

- Retrofitting is only the option to reduce structural vulnerability of the buildings.
- Seismic retrofitting of school buildings is technically, socially, economically and culturally feasible and needs to be given more and more priority to protect the children.
- The DOE needs to increase the number of qualified engineers and build capacity on vulnerability assessment and design for retrofitting.
- The Government alone cannot handle the problem of the safety of all schools. It needs to collaborate with the all the development partners, civil society, academia, expert community and the business sector.
- A participatory and community driven approach is the best way to enhance safety of public schools.
- Awareness is the key for the success and internalization of any risk reduction measures.
- Just the hardware part doesn't provide sustainability. Hence the software part such as orientation, training and general awareness components are to be integral part of the program.
- Need to develop more trained masons for the scaling up of SESP.
- There should be certain attractions to the masons to retain them in the country.
- A national level steering committee and a high level technical committee need to be established.
- This is one of the best awareness rising tools.
- Since more than 75% of the existing school buildings of Nepal are vulnerable to earthquake the Government needs to take immediate steps to address this issue.
- Till now the program has been implemented in the Kathmandu Valley, this need to be replicated to other parts of the country through appropriate mechanisms.
- A massive need for training and capacity building of different stake holders of the education sector is required for the scaling up of the program.
- A strong monitoring mechanism should be developed and peer review should be conducted each year.
- A national strategy for school safety needs to be implemented.

Earthquake Hazard Centre
Promoting Earthquake-Resistant Construction in Developing Countries

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