EARTHQUAKE HAZARD CENTRE NEWSLETTER

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Editorial

In the last couple of months the New Zealand Society for Earthquake Engineering has been conducting seminars around the country on the topic of non-structural elements. The Christchurch earthquakes of 2011 and 2012 provided many examples of where non-structural elements performed poorly. Most of the material covered in the seminars dwelt with claddings – how to design elements such as precast concrete panels to allow interstorey drifts without distress, and at the same time to withstand the inertia forces both in the plane of and normal to a panel. Stairs were also discussed. They must be separated, usually at their tops or bottoms with sliding joints. This is so they won't to act as unintended diagonal braces. If there is no separation of a stair, when a structure experiences interstorey drift, a stair will act as either a compression or a tension strut. It will almost certainly be damaged and could even damage the primary lateral load resisting system by inducing torsion. An important detail concerning separation is the width of separation gaps, and one of the points arising from these seminars was that the current method in the New Zealand Codes for calculating the sizes of gaps, under-estimates their widths.

In developing countries, approaches to restraining and separating non-structural elements are more difficult given the large amount of unreinforced masonry infills and partition walls that are used. The Nepal earthquake, earlier this year, left hundreds or thousands of buildings uninhabitable due to damage to masonry walls. Even where the primary structures consisted of say reinforced concrete moment frames, the buildings are considered unsafe due to the instability of internal and perimeter walls. For non-structural masonry walls, perhaps infills, after one or two cycles only of shaking, the bond between the sides and tops of the walls and the frame members crack. This leads to a strong likelihood of walls falling from their structural frames.

This damage would be far less likely to occur if designers specified steel reinforcement tying infills and partitions to primary structural elements. This reinforcement might take the form of vertical "practical columns" that are embedded in walls and are strong enough to resist the face load inertia forces acting on them. The role of the practical columns in the walls is to transfer inertia forces up and down to the frame members or the floor diaphragms above and below the wall. Alternatively, for shorter lengths of wall, horizontal steel might be embedded into mortar joints, forming horizontal 'bond beams'. This reinforcement needs to be placed regularly up the height of the masonry wall to form a series of beams that can transfer horizontal face loads to side members. This approach will also prevent wall face-load failure.

If designers do restrain unreinforced masonry walls against face load, these walls, including infill walls, will affect the structural behaviour of the moment frames. Randomly-placed masonry walls can create critical structural weaknesses like soft storeys, short columns and torsionally eccentric configurations. To avoid these serious potential failure modes the masonry walls should either be separated from the frames or seismic loads should no longer be resisted by frames, but by structural walls. For low-rise buildings, confined masonry should be considered as a replacement structural system for non open frames.

Virtual Site Visit No. 40. Precast concrete panelled and steel framed apartment building

This building under construction is located on the outskirts of Wellington's CBD. As can be seen from Figure 1, the structure consists of precast concrete tilt-up panels combined with steel moment frames. The majority of the gravity loads will be resisted by the precast walls, and they will be more than adequate for resisting transverse earthquake forces. That is, they will be very strong and stiff against forces acting across the width of the building. However, when longitudinal seismic loads occur, these panels are extremely vulnerably given their height and thinness. They require stabilizing. To achieve this, the designers have introduced two perimeter steel moment frames, one at the front, and the other at the rear of the building. These two frames resist all longitudinal loads. You can observe that, because they are only one storey high, the walls are designed to cantilever above the first floor level. This is feasible as the roof and all wall framing above first floor is of lightweight construction.

To ensure that longitudinal seismic forces can travel from the wall panels into the frames it is important that the first floor slab is strongly attached to the panels (Figure 2). The starter bars protruding from the panels will be bent horizontal and lapped with the first floor reinforcing that is placed over the precast floor slabs yet to be craned into place. A strong connection is also required between that floor slab and the beams of the moment frames. Now an effective force path exists between walls and frames. Figure 2 also shows a steel angle bolted along the sides of the wall panels. This member supports the ends of the precast floor units and transfers their gravity forces into the walls.

The bottoms of the wall panels need to be tied to the ground floor slab which may also help transfer gravity forces from the walls into the underlying foundation material. Figure 3 shows the starters that will be bent horizontal and lapped with the main ground floor slab reinforcing.

Figure 1. Overview of apartment building under construction

Figure 2. Steel frame and panel to suspended floor connection detail.

Figure 3. Reinforcement at the base of a precast panel to tie it into the floor slab.

A Summary of "Safer Schools, Resilient Communities: A Comparative Assessment of School Safety after the 2015 Nepal Earthquakes" by Rebekah Paci-Green, Bishnu Pandey and Robert Friedman. *Risk RED*, August 2015.

BACKGROUND

Across Nepal, more than 8.5 million students attend pre-school through vocational school. As they learn, they sit in well over 82,000 school buildings at more than 35,000 school campuses. Approximately 75 percent of these campuses are public schools, built by the Ministry of Education and development partners.

Previous school safety studies carried out in the country estimated that approximately 89 percent of school buildings in Nepal as made of load-bearing masonry, a building type that is particularly vulnerable to earthquakes if no earthquake-resistant techniques are incorporated. In hilly regions more than 50 percent are the most vulnerable ma- sonry type – rubble stone construction. A 2011 school vul- nerability assessment estimated that because of Nepal's seismic risk, more than 49,000 schools needed to be retrofitted and another 12,000 needed demolition and reconstruction. This was before the 2015 Gorkha Earthquake and aftershocks struck.

Nepal has undertaken efforts to address the structural vulnerability of schools. School safety retrofit and reconstruction efforts had reached about 160 schools and training had reached almost 700 masons in the Kathmandu valley - only some of these in the area affected by the April and May 2015 earthquakes. Innovative public education and mason training programs over the past two decades have included mason training, community outreach, and shake-table demonstrations as part of training and awareness programs.

On April 25, 2015, a massive M7.8 earthquake struck West- ern and Central Nepal, with an equally devastating after- shock of M7.3 striking in Central Nepal on May 12, 2015, as measured by the United States Geological Survey. According to the Government of Nepal Ministry of Education, the Gorkha Earthquake caused more than 27,000 classrooms to be fully destroyed by these events, and more than 26,000 classrooms to be partially destroyed. The cost of education sector recovery is estimated at almost $415m USD.

Purpose & Approach

The effects of the earthquake on Nepal's educational infrastructure offer a rare opportunity to study whether previous interventions to improve building practices, combined with community engagement, have resulted in safer schools and communities. The primary questions we considered were:

- How did damage at purportedly disaster-resistant public school buildings, whether retrofitted or newly constructed, compare to damage of typical public school buildings?
- What affect, if any, did community engagement around safer schools have on risk awareness and community construction practices?

In Bhaktapur, Kathmandu, Rasuwa, and Sindupalchowk, we compared three, geographically proximal public schools:

- **No intervention** — typical construction
- **Technical intervention only** — disaster-resistant design or retrofit
- **Technical and social intervention** — disaster-resistant design or retrofit, combined with community engagement

At each site, we conducted interviews with school staff and management committees, parents, and lead masons involved in school construction. We also visually assessed school buildings and 15-20 nearby houses for damage.

KEY FINDINGS

'Comprehensive School Safety,' a framework adopted by United Nations agencies and humanitarian organisations in the education sector, seeks to ensure children and school personnel are not killed or injured in schools, and that educational continuity is assured. It rests on three overlapping pillars of safe learning facilities, school disaster management, and risk reduction and resilience education. Field observations are reported in relationship to these three pillars:

Pillar 1

- School buildings retrofitted to be earthquake generally perform better than school buildings built without these considerations.

- School buildings designed or retrofitted to be earthquake resistant, but constructed without adequate mason training or technical oversight, performed poorly; some collapsed.
- Stone walls observed collapsed, even when retrofitted or built with some earthquake-resistant features.
- Unreinforced brick and stone infill walls were the primary damage in areas of moderate shaking. This damage rendered school buildings unusable and posed significant risks to occupants.

Pillar 2

- Where schools were retrofitted without community engagement, many students and staff planned to run out of their safe schools, causing unnecessary injury and death.
- In schools with load-bearing stone walls, neither evacuation during shaking nor Drop, Cover, Hold would have protected students. Staff now distrust the Drop, Cover, Hold message.
- Some children and adults incorrectly ran into unsafe stone buildings to drop, cover, and hold; they were killed.
- Lack of non-structural mitigation in some schools resulted in loss of computers and science lab supplies.

Pillar 3

- Community engagement built trust in the projects. Without engagement, projects were misunderstood.
- Those at community engagement sites showed better knowledge of risk and earthquake-resistant construction technology. New housing was reported to have incorporated some of these technologies.
- With community engagement, some school staff became advocates for safer construction, but effects were limited where school staff did not share cultural and language ties with parents.
- Impacts of the safer school projects faded over time. Safer school buildings lacked signage or displays to educate new families about the earthquake-resistant retrofit or new construction features.

RECOMMENDATION HIGHLIGHTS

All children deserve safe, accessible and culturally appropriate school buildings — regardless of class, creed, gender or ability. A community-based approach to safer school construction seeks to achieve the twin goals of safer schools and more resilient communities. It treats school construc- tion as a community learning opportunity to better understand risks, collectively commit to safety, and to learn and apply strategies for safer construction.

Figure 4. At a school in Kathmandu, two school buildings on the same sight performed very differently. The building on the left, a reinforced concrete frame structure with brick infill walls, was moderately damaged and received a red tag. Its frame joints and infill walls will need to be repaired before the building can be reused for classrooms. The building on the right, an adobe and stone masonry structure, was recently retrofitted with stitch banding. It was undamaged and immediately able to be reopened, despite being made of a weaker building material. The retrofit proved to be successful.
Photo: R. Friedman/ Risk RED

A community-based approach builds community capacity in tandem with the laying of foundations and erecting of classroom walls. It also prepares communities to be knowledgeable caretakers of schools, able to maintain the physical safety of the structures and the culture of safety among those who use it:

Mobilisation

- Media campaign to promote the idea that schools and housing can be built earthquake-safe.
- Mobile technical resource centres in each district to showcase safer construction technology and provide technical assistance to school management committees and communities.

Planning

- Review and revise school template designs.
- Train district engineers in retrofit options.

Figure 5. School building 101-1, which experienced only moderate shaking in Bhaktapur, was deemed unsafe for school use because unreinforced partition walls separated from the reinforced concrete frame and became unstable. Damage to unreinforced partition or infill walls can injure or kill students and block exits. The safety of these walls is routinely ignored by engineers and communities alike.
Photo: R. Paci-Green/Risk RED

- Limit use of rubble-stone walls in school construction until clear guidance, training and oversight is in place.
- Retrofit unsupported brick and stone infill walls.

Design

- Ensure all independently-funded schools are reviewed for safety.
- When safe and feasible, choose construction materials familiar to community for better maintenance and technology transfer.
- Limit community-level design changes to aspects that will not impact safety.

Construction

- Mason training and certification.
- Release school construction funds in stages after verification of construction quality.
- Construction process videos for better public understanding of good school construction.
- Public notice boards and curated site visits for parents and community.
- Community checklists for disaster-resistant construction, with robust mechanism for reporting problems.

Post-construction

- Establish school disaster management committees and provide them with regular training and guidance.
- Integrate safer community planning and construction into curriculum and school-to-community outreach.
- Label school safety features prominently for enduring impact.

PLANNING

Planning for school reconstruction in Nepal needs to be based upon evidence from this most recent earthquake. Many of the template designs and oversight processes proved ineffective at achieving life-safe school buildings. Recommendations for improving the safety of school buildings constructed include:

- Review all Ministry of Education template designs based upon damage patterns observed. Address obvious design and construction flaws – weak columns, unsupported infill, etc. Revise designs prior to authorizing reconstruction. In the review, address the non- structural hazards of unsupported infill walls and develop simple retrofit recommendations for existing infills.

- Rapidly assess rubble stone school construction, including 'non-structural' rubble-stone infill or perimeter walls. Assess the limitations of this material and what, if any, earthquake-resistant techniques can achieve minimum life safety. Place a temporary moratorium on rubble stone and mud mortar school construction until guidelines, training, and supervision in safer rubble stone construction have been put into effect.

- Develop continuing education training program for district department of education engineers and engineering technicians' on disaster-resistant design and construction, in collaboration with community mobilizers and contractors. Highlight key principles and construction details that they must carefully review for safer school reconstruction (concrete mix, curing, lap splicing, transverse reinforcement, banding in masonry construction, etc.). Promote professionalism, including by reviewing pay scales.

- Develop public awareness videos on safer school con- struction. Patterning after reality TV programs may prove to be particularly exciting for viewers – the program could follow the construction of a safer school or home, including experts that came in to expose errors or reward those who constructed correctly. Short technical reference videos viewable on smartphones may also provide important reference material for masons and general public.

- Convene a multi-stakeholder taskforce to review community oversight and contribution to school construction. The taskforce should look for ways to preserve

- Nepal's good practice in local governance of schools, but address the challenges that have resulted in unsafe schools (e.g. unequal access to resources, local capacity, and corruption).

- Plan for transparency by developing simple guidance and checklists for budgeting and procurement tracking. Pilot and seek feedback from school management committees to understand where they most desire support. Establish a remote technical ombudsman to respond to queries and photos and to also flag concerns. (Smart phone apps may be particularly effective in this area).

- Develop mechanism for independent and external review, e.g. through an independent construction inspec- tion firm or district office engineers.

- As a matter of policy, apply all practices associated with safer school facilities to both public and private schools for early childhood through secondary education.

DESIGN

Had the earthquake struck during school hours, much of the loss of life and injuries would have come from brick and stone walls. The engineering field has often ignored infill walls as non-structural elements that can be relegated to architectural detailing. Design engineers and even building codes have let non-technical people decide how and where to place these walls. Ignoring the performance of infill walls in earthquakes is a deadly one, as school damage shows. The Nepalese engineering community and international organisations that propose school template designs for Nepal need to fully consider these infill walls in approved designs and in construction site inspection. They must account for infill wall performance and failure in deciding whether a school building will be life safe in future earthquakes. Not to do so is to put the lives of thousands of students and staff at risk.

The DOE capacity in seismic engineering should be enhanced so that district-level engineers and sub-engineers can better assess the failures of past school construction in their districts and develop locally-feasible solutions. Capacity-building is especially needed around issues of infill walls and approaches to the retrofit of moderately damaged schools. Discussions with district engineers indicate there is little current capacity in these two areas but a strong desire to learn.

While the designing of safer schools needs to be conducted by trained and competent engineers, community engagement is still crucial to the success of a safer school. The past practice of communities radically altering designs during construction – adding extra floors, changing the location of columns and beams – needs to stop. Communities need to understand how this past practice resulted in unsafe schools for their children. Recommendations for this stage include:

- Ensure all school designs are reviewed by knowledgeable Ministry of Education engineers or their delegates, including those built through INGO and private donor support. With this review, the Ministry should take full responsibility for the safety of its school designs.

- Create a school design review process where a panel of competent technical organisations or structural engineering firms assess the appropriateness of the selected design for the site, local materials, community capacity, and hazard exposure. Such review should apply to original designs, ministry template designs, private school designs, and designs provided by INGOs and development partners.

- Provide communities with design choices that will not impact safety (e.g. choices in architectural layout, some construction materials, architectural finishes, colour, etc.). Clearly designate and explain what design changes communities cannot make because of their impact on school safety (e.g. additional floors, changes in column/beam/bearing wall layout, construction of unsupported partition walls, etc.)

- Train district engineers charged with site supervision in techniques for explaining disaster-resistant construction methods to school committees, parents, and local masons. Provide educational props – posters, pam- phlets, visual demonstrations using readily available materials or body motions.

- Whenever feasible and safe, choose school reconstruction designs using materials that are familiar to the community to enhance maintenance and transfer of concepts to housing. Where local materials are not feasible or safe, construct small demonstration build- ings with local materials as part of, or in coordination with, the safer school construction project or housing reconstruction activities.

CONSTRUCTION

Good planning and design can be completely undermined during the construction stage. Much of this event's dam- age, especially in reinforced concrete construction, stemmed from poor construction practices – ad hoc concrete mixing, improper curing of concrete or cement mortar, improper reinforcing steel detailing, and unconsolidated concrete. Because many communities erroneously believe that concrete construction is universally safer than masonry construction, regardless of whether it has disaster-resistant design and construction detailing, the reconstruction of schools needs to build knowledge about disaster-resistant construction of all material types, but especially reinforced concrete.

Also important will be readjusting community participation expectations during the construction stage. While community support strengthens community

Figure 6. This teaching resource centre on school grounds was built with stone and mud mortar. The masons employed earthquake-safety measures, such as a reinforced concrete lintel band and vertical reinforcement in the walls. However, even with these measures, the heavy shaking in Sindhupalchowk caused the stone building to collapse swiftly and completely. It may be difficult to rebuild safe schools out of this brittle material unless alternative technologies are developed, tested and extensive mason training and strict oversight are feasible during construction.
Photo: R. Paci-Green/Risk RED

cohesion and may be a necessity in remote and rural communities, participation should be encouraged in areas that do not negatively impact structural safety.

Where communities do contribute to crucial aspects of the construction, they will need better technical support. Community support mechanisms need to also encourage robust transparency to dampen corruption that can impact the safety of the school building constructed.

- Provide broad construction training in earthquake resistant construction and retrofitting and require certification for any masons or unskilled labourers working on school construction projects.

- Require that a certain portion of all construction workers working on school construction are local, and are trained and certified, so that good construction knowledge has a better chance of staying in the community and transferring to housing reconstruction.

- Disseminate construction process videos to build community-wide knowledge and demand for safer con- struction.

- Provide school committees and parents with checklists for identification and selection of high quality materials.

- Provide school committees and parents with checklists for identifying disaster-resistant construction techniques, for a range of building typologies.

- Encourage committees and parents to contact ombudsman when low-quality materials or improper construction techniques are identified. Confirm that communities know how to access this independent review mechanism.

- Release school construction funds in stages and tie each release to the school management committee and contractor successfully demonstrating that construction to date is following design drawings, especially in regard to the detailing that impacts the safety of the completed school building.

- Ensure INGOs engaging in school construction employ on-site construction supervision, either through their own technical staff or certified construction managers.

- Focus community participation on non-technical contributions (e.g. site donation, site preparation, gathering or transporting materials, architectural finishes, documenting construction process).

- Support school management with mechanisms for transparent accounting. Include parents and older students in construction oversight to promote transparency. This will also ensure that communities learn about availability and cost of materials, information also useful for their own housing construction.

- Ensure school construction projects include regular, curated site visits for parents and community so they can closely inspect the disaster-resistant features of the school as it is being built.

- Require a public notice board at each school construction site. The board should explain in clear language the earthquake, landslide, and flood-safe features of the design.

- Where possible, apply finishes to school buildings that strongly highlight disaster-resistant elements, for example by painting columns, earthquake bands, roof ties and similar elements in bright colours.

- Document the school construction process to be part of a hard-back school construction history book, with inputs from the school community.

Earthquake Hazard Centre
Promoting Earthquake-Resistant Construction in Developing Countries

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