



COMPARATIVE ASSESSMENT OF PERFORMANCE OF SCHOOL BUILDINGS IN THE 2015 GORKHA (NEPAL) EARTHQUAKES

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Abstract

The 2015 Gorkha Earthquakes (M7.8 with M7.3 aftershock) destroyed more than 27,000 classrooms and damaged more than 26,000 classrooms in Western and Central Nepal. Several studies in the past had shown the vulnerability of the education infrastructure, resulting from insufficient earthquake resistant elements in school construction. Most of these schools were unreinforced masonry or non-ductile reinforced concrete frame buildings. Since early 2000, several schools have been seismically upgraded and other schools were reconstructed to meet the minimum building standards for seismic loading. The Gorkha earthquakes provided a rare opportunity to study whether those seismic upgrades or rehabilitations had, in fact, improved earthquake resistance as intended.

A study was carried out in the aftermath of the earthquakes to comparatively assess school buildings in four different areas characterised by low, moderate and high shaking intensities. A total of 25 school buildings were assessed in 12 school sites. Field surveys were carried out on school buildings, both those with conventional construction and those with seismic resistant features. Assessed school buildings included stone masonry with flexible and rigid diaphragms, brick masonry, steel truss buildings with brick and stone infill, and reinforced concrete construction. A transect survey of residential housing damage was also carried out around each school site.

This paper describes the results of the assessment and presents the key elements (or lack thereof) that govern the seismic performance of school buildings in Nepal. While most of schools buildings with seismic upgrading – including simple interventions like selective reinforcement, micro-concrete wall jacketing – performed well in the earthquakes, some other buildings retrofitted or considered to be earthquakes-resistant construction were damaged severely. In addition to structural factors in design and construction, the study also looks the aspects of construction standards and norms, technical oversight, quality of material and resource constraints that played role in earthquake-resistance of school buildings. The paper presents a review of those design and construction considerations and establishes key considerations for construction of earthquake-resistant schools in regions with high seismicity and significant resource constraints.

Keywords: schools seismic safety; post-earthquake damage assessment, retrofitting, masonry

1. Introduction

The M7.8 Gorkha Earthquake on April 25, 2015 and its aftershocks including M7.3 on May 12 hit hard 14 districts of Nepal across its Western and Central regions. Education sector was among the hardest hit of the disaster. A total of 8,242 public schools were damaged in the earthquake with an estimated losses of US\$313 million in education sector alone [1]. The earthquakes destroyed more than 27,000 classrooms and damaged more than 26,000 classrooms and interrupted the education of approximately 1 million children Nepal.

When the Gorkha Earthquake struck on Saturday noon of April 25th, 2015, the schools were closed and huge fatality among children was thankfully missed. However, it became clear from the damage assessment that the loss of infrastructure due to destruction of school facilities was immense and impacts to education sector were pronounced [2].

While the earthquake mostly destroyed school buildings built with no earthquake resistant elements in design and construction, it also tested hundreds of school buildings that were seismically upgraded in recent years. Unlike in most low-income countries where school retrofits are initiated only after a devastating earthquake, Nepal had been retrofitting schools for nearly two decades, thanks to advocacy and initiation by



dedicated group earthquake engineering and subsequent program that government implemented with supports from donor community.

In 1999, the National Society for Earthquake Technology-Nepal (NSET) began pioneering school retrofit projects to reduce the risk of school collapse in anticipated earthquakes. NSET's motivation for school safety was not limited to physical protection of school buildings but also to introduction of earthquake safe technology to the society through school system, a strong and visible platform in the communities. Schools could also serve as an opportunity for local masons and residents to learn how to build safer houses using familiar construction materials [3].

The 2015 Gorkha Earthquake provided an opportunity to assess the approach and method of Nepal's school retrofitting. The effects of the earthquake on Nepal's educational infrastructure serve as field test to study whether previous interventions have resulted in safer schools. In June of 2015, we conducted field assessments and interviews at 12 public school sites. The assessment compared schools that had been retrofitted or newly built as earthquake-resistant with schools built conventionally through the standard Ministry of Education design and construction process [4].

Nepal's school losses offer a rare opportunity to ask whether simple technical strategies adopted have resulted in safer schools. The primary question considered was: how did damage at purportedly disaster-resistant public school buildings, whether retrofitted or newly constructed, compare to damage of typical public school buildings with no intervention? The study included visual assessment accompanied with interviews of technical persons involved in school construction. In the study, it was also explored whether school retrofit projects do more than physically strengthen a school building and served as change agent to the community towards broader earthquake safety. The second aspect school retrofitting was discussed elsewhere [5]

2. URM School Buildings and Their Retrofit

The seismic upgrade of school buildings in Nepal focused mostly to unreinforced masonry wall buildings. A study conducted by NSET in 1999 on public school building stock in Kathmandu valley before launching their school retrofitting showed that more than 60% of buildings were built using traditional materials such as adobe, stone rubble in mud mortar or brick in mud mortar [6]. The remaining school buildings had brick in cement mortar with no reinforcement and only 11% were reinforced concrete with URM infill. Traditional artisans build almost all of these schools without any inputs from an engineer. The major problems of the buildings was lack of connection between different components [7]. Orthogonal walls were not structurally connected, flexible floors were constructed of timber planks or bamboo strips supported on simply on timber joists. These joists were not tied up to the walls. Roof made of CGI sheets on timber battens were not firmly connected to walls. Gable walls were not tied to roof structures. Hence buildings were most like stacked material without interconnection. They were susceptible to losing integrity even in small shaking. As floors and roofs were flexible, the orthogonal walls do not provide stability in lateral shaking. The unreinforced walls may fail in out-of-plane and also in-plane damage is expected they don't have enough shear and flexural tension resistance.

Because of the inherent weakness of the URM school buildings and socio-economic condition of the society of the developing country, strategy of seismic intervention to those buildings should have considered affordability along with safety. That demanded a simple and cost effective seismic upgrade with use of local material avoiding any complex construction system. NSET started seismic upgrade of URM school buildings with selective reinforcement in splint and bandage along with stitching of orthogonal walls. The focus was to enhance the integrity of the building. The connection between orthogonal walls were improved by continuous reinforced micro concrete strips in the corners and T- junctions. The vertical continuous strips, called splints, were provided from foundation to roof level. Similarly horizontal strips, called bandages were provided to run horizontally around all the walls on both side of walls. The splints and bandage were 50 mm thick reinforced micro concrete section applied on bare wall after racking mortar from the brick work joints. The two face of bandages were connected using staggered dowel bars. The bandages were provided at sill and lintel levels. Figure 1 shows a typical construction of splint and bandage.

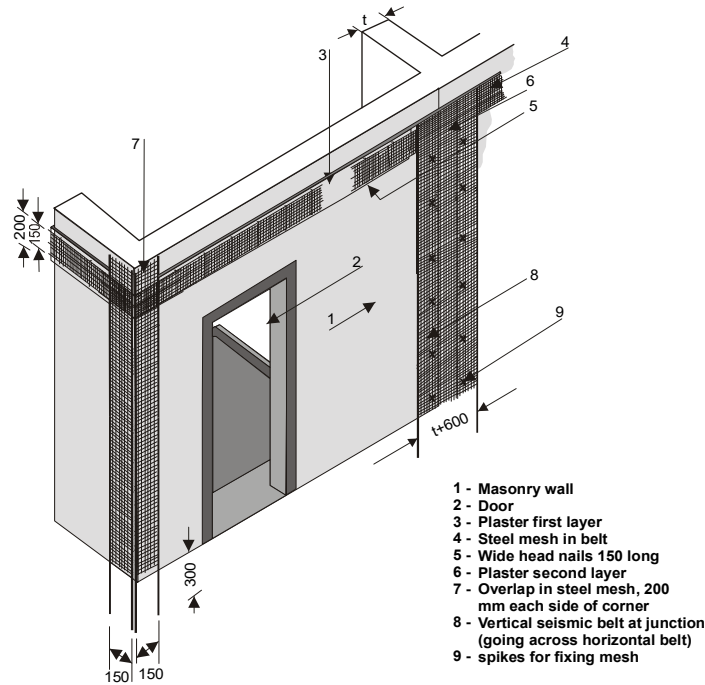


Fig. 1- Splint and bandage technique of retrofitting of unreinforced masonry wall [8].

Figure 2 shows the actual construction process in Bhuvaneshowri School Bhaktapur, the first retrofitted school in Nepal. The timber floors were replaced by thin concrete slab to make the rigid diaphragm. The roof battens were braced and tied to wall at the roof band. Gable walls were also reinforced and anchored to the roof system. This system of seismic upgrading is typically applied in URM schools buildings. In some schools the micro concrete cover is applied in the entire wall in the form of jacketing.



(a) Before construction



(b) During construction



(c) After construction

Fig. 2- Application of splint and bandage technique of seismic retrofit in URM school building in Nepal

New construction with earthquake resistant element in masonry construction includes reinforcement in seismic bands at lintel and floor levels. These new construction were typically include reinforced concrete floor.

3. Survey Method

We selected four districts from within the impacted region where retrofit and new earthquake-resistant school construction projects had taken place. Two districts, Bhaktapur and Kathmandu, were within the Kathmandu Valley, where school retrofit programs have been carried out by several agencies including the government that started its school retrofit program in 2011. In these districts, the general damage by earthquake to the built-environment had been moderate to heavy. Because most of the damage and heavy shaking intensity occurred in



the hilly and mountainous regions of Western and Central Nepal, we selected two of the most heavily damaged rural districts as our remaining locations – Rasuwa and Sindhupalchowk. These were one of the few places where NSET had completed safer school construction projects within areas of moderate to high intensity shaking during the Gorkha Earthquake.

In each of the four districts, we selected three public schools for the study in close physical proximity, typically within the same Village Development Committee. These schools represented three cases:

- i. **Standard Construction.** The first case in each district was a school, chosen from the Nepal government's Ministry of Education (MoE) database, which had been constructed through standard school construction processes. The school under this category generally lacks earthquake resistant elements in design and construction.
- ii. **Technical Intervention.** The second case was school that had been retrofitted or designed for earthquake resistance, but where the technical intervention had been accompanied by little or no technology outreach to surrounding community. In the Kathmandu Valley, the selected school retrofit projects had been managed directly by the District Offices of Education. The retrofit was carried out by outside contractors and technology transfer aspect is minimal. In Rasuwa and Sindhupalchowk, the school construction or retrofit had been funded by international non-governmental humanitarian organizations.
- iii. **Technical Intervention with Community Outreach.** The last case in each district was an NSET project school where technical intervention had been combined with community engagement in planning, design and construction.

The selection of schools was facilitated by the National Society for Earthquake Technology-Nepal (NSET)'s electronic list of school locations and retrofit status. Where multiple such schools existed, we selected the school with highest enrolment as these schools often had several school blocks, which allowed for direct comparison of building damage and documentation of multiple school construction projects at a single site. All schools were selected based upon the pre-determined selection criteria, without knowing the level of damage school buildings had sustained. In each district, the three schools were less than 5 kilometres apart to ensure that distance from the epicentre and shaking conditions could be considered substantially similar. Table 1 below provides a general overview to the 12 school sites.

In some cases, different blocks in the same school site provided comparative assessment between buildings. These blocks usually were built from different resources using different method. Figure 3 shows an example of Kathmandu school site where blocks with different construction system behave in the earthquake. Here, two blocks built at same time performed very differently as one block was of unreinforced masonry wall upgraded later for seismic enhancement and other block with reinforced concrete. The reinforced concrete block with no seismic upgrade was moderately damaged and received a red tag. It will need to be repaired before it can be reused for classrooms. The block on the right was recently retrofitted with splint and bandage. It was undamaged and immediately able to be reopened.



Fig.3 – Two blocks in same school received different damage in the earthquake.



Table 1 – Overview of school construction and intervention projects assessed

Dist.	School code	Building type (main block)	Year of original construction/intervention	Intended technical intervention	Community outreach	Damage
Bhaktapur	101	2 storey RC-frame	2008	None	None	Infill wall damage
	102	2 storey retrofitted masonry	2003/2008	Retrofit	None	No damage
	103	2 storey retrofitted masonry, no damage	1987/2000	Retrofit	Mason training, onsite technical oversight, community outreach	No damage
Kathmandu	201	3 story RC-frame	2004-2010	None	None	Infill wall damage
	202	2 story retrofitted masonry	1993/1998	Retrofit	None	No damage
	203	2 storey, retrofitted adobe	1984/1991	Retrofit	Mason training, onsite technical oversight, community outreach	No damage
Rasuwa	301	1 storey metal frame	2005	None	None	Infill wall collapse
	302	1 storey retrofitted stone	1997/2011	Retrofit	Limited mason briefing	complete collapse
	303	2 storey earthquake-resistant masonry	2008, unauthorized addition 2011	Resistant, new	Mason training, onsite technical oversight	No damage
Sindhupatchowk	401	2 storey stone	1992	None	None	Complete collapse
	402	2 storey earthquake-resistant RC frame	2013	Resistant, new	INGO funds specific design development DUDBC	Complete collapse
	403	2 storey earthquake-resistant masonry	2004	Resistant, new	Mason training, onsite technical oversight,	No damage

We visited each school site for a full day of interviews and observations. These included 1-2 hour visual assessment of school and 2-3 hour survey of neighboring houses. We conducted 2-3 hour semi-structured interviews with school principals where we asked about their earthquake experience, and the detailed questions about the funding, design, construction, and construction oversight of one to three representative school blocks. We conducted interviews with the lead mason or lead masons responsible for the earthquake-resistant school construction project. Masons were also asked about construction techniques they implemented in local housing construction and their observations about building damage in the earthquake. We also conducted a focus group discussion with local parents of students attending the school. Activities and observations from interviews with school community and parent focus group are described elsewhere [4].

4. Observations

Our field observations begin to explain some of the reasons for the damage and to differentiate between standard, retrofitted, and purportedly earthquake-resistant new construction.

4.1 Standard Construction

When schools were built through the standard construction process, they generally could not be immediately re-occupied. Some collapsed, as shown in Table 2. Reinforced concrete (RC) school construction and metal frame



construction surveyed generally had minor or moderate structural damage. However, damage to the infill walls was often moderate to heavy. These damaged infill walls caused the school buildings to be closed. Stone and brick school buildings constructed through standard processes generally collapsed.

Table 2 – Observed damage to schools built through the standard construction process

District	School-Block No	Structural System	Wall Type	Intervention	Color code tag	Overall Damage
Bhaktapur (Moderate Shaking)	101-1	RC Frame	Unreinforced brick	None, recent engineering graduate designed	Red	Infill wall instability renders building unusable until repaired
	101-2	Metal Frame	CMU block, unreinforced	None, template design	Red	Infill wall instability renders building unusable until repaired
	101-3	Metal Frame	CMU block, unreinforced	None, template design	Red	Infill wall instability renders building unusable until repaired
Kathmandu (Moderate Shaking)	201-1	RC Frame	Unreinforced brick	Unclear, INGO designed and funded	Green	None
	202-1	RC Frame	Unreinforced brick	None, local engineer designed	Red	Infill wall instability renders building unusable until repaired
	203-2	RC Frame	Unreinforced brick	Unclear, INGO designed and funded	Red	Moderate damage to frame joints; Infill wall instability
Rasuwa (Heavy Shaking)	301-1	RC Frame	Stone/Cement	None, template design	Red	Infill wall instability renders building unusable until repaired
	301-2	Metal Frame	Stone/Mud	None, template design	Red	Collapse, exterior and partition walls
	303-1	RC Frame	Stone/Cement	None, template design	Red	Infill wall instability renders building unusable until repaired
Sindhupalchowk (Heavy Shaking)	401-1	RC Frame	Unreinforced brick	Unclear, INGO funded, unclear who designed	Red	Heavy, non-ductile failure of joints, collapse of parapets
	401-2	RC Frame	Unreinforced brick	None, int'l donor funded, design through District local govt.	Red	Heavy damage, non-ductile failure of joints
	401-4	Metal Frame	Unreinforced brick	None, template design	Red	Heavy damage and collapse to exterior masonry infill
	402-1	RC Frame	fired brick, unreinforced	None, INGO funded, community designed	Red	Infill wall instability renders building unusable until repaired
	402-2	Wall	Stone/Mud	None, INGO funded, community designed	Red	Collapse, complete
	403-2	Metal Frame	Unreinforced brick	None, template design	Red	Infill wall instability renders building unusable until repaired
	403-3	Metal Frame	Unreinforced brick	None, template design	Red	Partial infill wall collapse
	403-4	Metal Frame	Unreinforced brick	None, template design	Red	Partial infill wall collapse
	403-5	RC Frame	Unreinforced brick	None, int'l donor funded, community designed	Red	Infill wall instability renders building unusable until repaired



4.1.1 Infill Wall Damage

Infill walls had unreinforced brick or stone walls which form exterior walls or to partition classrooms. During the earthquake, many cracked where connected with beams and columns. Others developed more noticeable damage at corners or even diagonal shear cracks. At the schools observed, the infill walls did not have vertical or horizontal reinforcing steel to support them, a common practice prescribed by international building codes and NBC as well. When they cracked, as is expected in an earthquake, they became unstable because of the lack of reinforcing or other means of holding the walls in place.

These infill wall cracks, although considered minor damage from a structural engineering perspective, were a serious problem in schools (Figure 4). Teachers and principals would demonstrate by pushing on the cracked walls, causing the walls to visibly move. With the risk that these walls could topple over and crush occupants in large aftershock or future earthquake, many schools with infill wall damage were given ‘red tags’ by Ministry of Education inspectors. A seemingly minor damage relegated untold thousands of students and staff to temporary learning spaces and tents.

Two ubiquitous school template design approved by the Ministry of Education performed particularly poorly. The first was a metal frame supporting a corrugated metal roof, a design originally developed by a major bilateral development assistance agency. While the metal frame and roof were undamaged, the communities report that they were told to build exterior walls in whatever local material was available.



Fig. 4 - School building 101-1 experiencing only moderate shaking deemed unsafe.

In semi-urban and urban areas, communities built unreinforced brick walls around the frames; in rural areas, they often used stone and mud to build the walls. A review of the design drawings of one of these structures does show detailing for a reinforced concrete lintel band on the top of the walls and reinforcing at wall connections. However, these elements of the design were not observed in any of the six metal frame school blocks we assessed. In moderate to high shaking, these walls partially or completely collapsed and would have killed children unnecessarily had school been in session. School building 101-1 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. The safety of these walls is routinely ignored by engineers and communities alike.

The second design, derived from NBC provisions added vertical reinforcing bars at every wall and openings corner within stone and mud mortar walls. We found bands used in some of the schools built with this design, but not others. In all schools observed with this design, the bars proved ineffective and the stone fell away from the bars. These buildings completely collapsed (Figure 5).



Fig. 5- A Ministry of Education template design, which called for vertical rebar to be placed in stone walls, completely collapsed in every block assessed with this design.

4.2 Schools with Technical Interventions

School buildings that were said to be designed or retrofitted for earthquake safety generally performed better than other buildings, but not always (Table 3). In the moderate intensity shaking of the Kathmandu Valley, the retrofitted and earthquake-safe schools observed were completely undamaged, even while other school buildings at or near the school experienced minor or moderate damage. In the heavier shaking of Rasuwa and Sindhupalchowk Districts, school building performance was most variable. Only some of the supposedly safer schools performed better than similar school buildings nearby.

Table 3 – Observed damage to schools built or retrofitted with earthquake resistance

District	School- Block No	Structural System	Wall Type	Technical Intervention	Community Outreach	Color code tag	Damage
Bhaktapur/ Moderate Shaking	102-1	Wall	Unreinforced brick	Retrofit: Stitch banding	None	Green	none
	103-1	Wall	Unreinforced brick	Retrofit: Stitch banding	Mason training, onsite technical oversight, community outreach	Green	none
Kathmandu/ Moderate Shaking	201-1	Wall	Adobe	Retrofit: Stitch banding	Mason training, onsite technical oversight, community outreach	Green	none
	203-1	RC Frame	Unreinforced brick	Retrofit: Stitch banding	None	Green	none
Rasuwa/ Heavy Shaking	302-1	Wall	Brick/Cement	New: Banding and vertical reinforcement	Mason training, onsite technical oversight, community outreach unsuccessful	Green	none
	303-2	Wall	Stone/Mud	Retrofit: Stitch banding in stone	Limited, trained mason sent for two days, INGO	Red	Collapse, complete



					engineer inspected construction once		
Sindhupalchowk/ Heavy Shaking	401-3	RC Frame	Unreinforced brick	New: Original (non-template) RC design, staff told school would be earthquake resistant	INGO funds specific design development DUDBC but then modified on site, no mason training, limit gov't inspection	Red	Collapse, complete
	401-CC	Wall	Stone/Mud	New: Banding and vertical reinforcement	Community center on school compound	Red	Collapse
	403-1	Wall	Brick	New: Banding and vertical reinforcement	Mason training, onsite technical oversight, some community outreach limited by civil war	Green	None, hairline cracking

While the four retrofitted schools in Kathmandu and Bhaktapur were undamaged, we found several lapses in design or construction at one of the Kathmandu retrofits during our detailed visual assessment. At the base of the walls, the masons had created a stitch band beam. However the band was discontinuous on one side of the block; vertical bars came down and poked out of the bottom (Figure 6). While this school performed well in this earthquake, retrofit design and construction flaws may lead to unnecessary damage in larger events. In the left photo, vertical bars poke out the bottom of a retrofit band. A horizontal retrofit band at the bottom of the wall is missing on this side of the building. On the roof top, the vertical bars are secured by only small patches of concrete, partially covered in the photo by discarded school benches. The masonry columns supporting the roof overhang were not strengthened in any way and remain unsupported below the balcony overhang. On the roof, vertical bars continued up through the ceiling slab and were bent over only a short distance. The ends of the vertical band bars were covered with a small 16-inch patch, leaving only 8 inches for bars to be bent in each direction. The distance was too small to allow the bars to develop their full strength during an earthquake. In a stronger earthquake, the bars would have popped through the small roof batch. More globally, the retrofit addressed the masonry walls of the school only. The retrofit did not jacket and strengthen masonry columns on the second floor balcony or add supports below the masonry columns. Without strengthening these masonry columns, these masonry columns could crumble in a larger earthquake, leaving the overhanging ceiling and floor slabs unsupported and in real danger of collapsing during the earthquake or when students filed out to evacuate.

A retrofit of a rubble stone school in Rasuwa fared even worse – it completely collapsed. The block had been retrofitted by a major INGO using stitch banding technology and the community had been told the school would be safer than any new construction. The project included little training and oversight, and even less adaptation to the limitations of the brittle stone building material. The donor organization sent a trained mason to the site for only two days to train local workers, none of whom had professional training as masons. During the middle of the construction process, the donor’s engineer came only once, briefly. Local workers found it impossible to adapt the stitch band retrofitting technique to stone masonry; they simply could not drill through the stone walls to stitch bands together, but the project implementation had no plan for adjusting the technology or stopping an unsafe solution. The result was a catastrophic collapse (Figure 7). Donor-funded retrofit of a stone and mud mortar school in Rasuwa collapsed in the earthquake, as the principal captured and showed us on his smart phone. The left of Figure 6 was before earthquake and right is just after the earthquake. The rubble had been removed by the time of the survey. Little training of masons and nearly non-existent technical oversight ensured that when masons struggled to implement the retrofit design, the problems were not caught and rectified. The principal estimates 120 out of 140 students and staff would have died. Had technical experts been involved in community outreach, they may have better understood the challenges of stone retrofit in a remote village and may have modified or abandoned the project for something more likely to result in a safe school.



Fig.6 – Several design and construction flaws observed in a recently upgraded school building in Kathmandu.

Where local masons were appropriately trained and where trained engineers oversaw the construction practice by very frequent visits or continuous onsite presence, school performed beautifully. They were completely undamaged and few signs of poor construction practice were evident. In figure 8, the first was built without technical support. The second was built after the community was given an orientation on earthquake safe construction and local masons were trained in safer construction techniques. An engineer and lead mason, both with experience in earthquake-safe school construction, carefully oversaw the process. After the earthquake, the second was operational; even the terrace had been covered and converted into a makeshift workshop for the local community. Clearly, the social supports of training and oversight are crucial to achieving safe school construction in Nepal.



Fig.7 – Complete collapse of retrofitted school building in Rasuwa.



Fig.8 – Two neighboring schools in Sindhupalchowk both built through international donor support but taking different approach of community outreach for technology transfer.

4.2.2 Rubble Stone Construction

Rubble stone construction in schools is a vexing problem. It is a common local material and essentially free; in many mountain regions it is the primary construction material for schools and houses. Yet, to be used in school



buildings, it must be at least life safe since attendance is mandatory and safe evacuation of all students during shaking is impossible.

Most of the stone houses collapsed in the communities we surveyed. Most schools built with stone and mud mortar infill or load-bearing walls also collapsed, including the retrofitted school (albeit without appropriate training and oversight). Only when rubble-stone was used with cement mortar and as an infill wall for a reinforced concrete frame school building, did we observe rubble stone that had not partially or completely collapse. In Figure 9, a 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. A rubble stone teaching resource centre co-located on a school site provides additional reason for caution. The resource centre completely collapsed even though it had been built with important the earthquake-safe construction techniques commonly advised for load-bearing stone and brick construction. The resource centre had a lightweight roof, a reinforced concrete lintel band, and vertical reinforcement in the walls, though it did not appear to have a sill level band or corner stitches.



Fig. 9 - Complete collapse of stone masonry teaching resource centre building with concrete bands.

The widespread rubble stone collapses, even in a case where a lintel band and vertical reinforcement had been used, suggests that constructing safely with rubble stone is fraught with difficulties. Further research is needed to understand how other rubble stone schools with earthquake-resistant features fared and what technical and social intervention seem to have worked well. However, until further testing or comprehensive field assessment, extreme care should be taken in building infill or load-bearing walls with this material in permanent, transitional, or temporary school buildings. Further, even if safe and appropriate technologies for rubble stone are identified, school reconstruction with this material will need to be carefully supported with robust programs for training, oversight and community outreach so that safety is achieved in actuality and communities can trust that these stone buildings will not collapse.



5. Conclusions

The 2015 Gorkha Earthquake provided an opportunity to assess the approach and method of Nepal's school retrofitting. With comparative assessment of schools built with different approach and methods, following key observations made:

- School buildings retrofitted to be earthquake-resistant generally perform better when coupled with mason training and on-site technical oversight.
- A school retrofit observed, which had been implemented without trained masons and close technical oversight, collapsed.
- School buildings with specific earthquake-resistant designs were observed to have high variability in performance – mason training and close technical oversight was crucial to success.
- Stone walls with mud mortar observed were unsafe, even when communities attempted to retrofit or built with earthquake-resistant features. Further testing or field assessment is needed to assess whether earthquake-resistant techniques used with rubble-stone construction can achieve life safety in schools.
- Unreinforced brick and stone infill walls were a primary cause of school buildings being 'red tagged' or deemed unsafe for immediate re-occupancy.

Even in simple method of seismic upgrade when executed with enough technical oversight and technology transfer to the community results to a safe school promotes safe community from earthquake hazards.

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