INTRODUCING CONFINED MASONRY IN NEPAL

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Abstract

The April 25, 2015 M7.5 Gorkha earthquake and its aftershocks caused significant damage to buildings across much of Nepal. The hardest hit areas were the rural villages outside of Kathmandu, where over 770,000 houses were either completed destroyed or significantly damaged.

Most of the damage was due to the common use of structural systems that are inherently weak in resisting earthquake forces. Stone masonry with mud mortar is the most common structural system used in these villages. Unreinforced masonry and reinforced concrete frame with unreinforced masonry infill are also often used. These systems have a history of poor performance in earthquakes all around the world. They require a high degree of engineered detailing and a highly skilled work force to be able to build these buildings to be seismic resistant. In many villages in Nepal, however, most buildings are not engineered, are built by workers with little formal construction training, and are built for homeowners with limited financial resources. Thus there is a need to identify other structural systems that can work within these restrictions and also be more seismic resistant.

One potential option is confined masonry. Confined masonry has many similarities to concrete frame with brick infill construction already used in Nepal. It has a proven track record of seismic performance in many countries where strong earthquakes are common, particularly in Latin America and several Asian countries including China and Indonesia. Using confined masonry in the Nepal reconstruction could be an improvement to the existing construction practices and could potentially be introduced relatively easily. It will address two fundamental issues: the need of the country in the reconstruction of low-rise buildings, and the positive response from the general public on the earthquake safety of masonry buildings with concrete tie-columns and tie-beams.

There are several challenges to introducing confined masonry in Nepal. Confined masonry design and construction practices used in other countries must be modified to accommodate the conditions in Nepal and make the construction affordable using local materials and technology and be earthquake-resistant. Being unfamiliar with the technology, many concerned people at present may be reluctant to use a confined masonry system. The cost of confined masonry construction, in remote areas without transportation facility, may be higher in comparison to other systems that use local materials only. If these challenges can be overcome, then the people of Nepal would have access to more resilient construction technology.

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Keywords: reconstruction; technology; Nepal; confined masonry

1. Introduction

Nepal is the 11th most earthquake prone country in the world [1] and has experienced a major earthquake every few generations. The last great earthquake, the Gorkha Earthquake of magnitude 7.6 on the Richter scale, resulted in 8,000 deaths and 20,000 injuries [2]. The hardest hit areas were the rural villages outside of Kathmandu, where over 1,048,574 [3] houses were either completed destroyed or significantly damaged.

Most of the houses that were damaged or destroyed in the Gorkha Earthquake were built using structural systems that are inherently weak in resisting earthquake forces. They were also built by local builders using materials that are typically locally sourced and are inexpensive. Nepal is one of the poorest countries in the world and most of the rural villages are located in the mountains where the only access for vehicles are dirt trails that are prone to landslides and flooding. Thus the skills of local builders, the sources of building materials, and the cost of construction are critical factors that must be considered when determining how to rebuild the homes that were lost in the earthquake. Because of these conditions, it is infeasible to introduce more earthquake resilient seismic systems that were developed in other countries without alteration.

2. The Need for Improvement

2.1 Structural Systems in Nepal

There are three prevalent structural systems currently used for housing construction in Nepal: low strength masonry, cement based masonry, and reinforced concrete frame with masonry infill.

2.1.1 Low Strength Masonry Buildings

These are unreinforced masonry buildings with shear resisting walls made out of low strength masonry such as stone and adobe brick units, both with and without mortar. The typical floors and roofs in these structures are made out of timber or bamboo with mud overlay on the floors and either corrugated metal sheets, slate tiles, or wood thatch on the roofs. These buildings are typically two stories plus an attic. The inherent shear and tension capacity of these masonry units is low; moreover, the structure is not tied together properly, leading to it being vulnerable to earthquakes. These buildings are typically constructed by local builders utilizing locally available materials and using traditional knowledge passed down from one generation of builders to the next. More than 80% of the buildings affected by the Gorkha earthquake were of this typology.

Fig. 1 - A typical adobe house in Lele

Fig. 2 - A typical SMM house in Kavre

2.1.2 Cement Based Masonry Buildings

These are unreinforced masonry buildings with shear resisting walls made out of either burnt clay bricks, stones, or hollow concrete blocks. Cement-sand mortar is used for the walls. The typical floors and roofs in these kind of structures are either timber framed or reinforced concrete slabs. These buildings typically have thick walls and may have reinforced concrete bands at the floor level but usually no bands at the lintel or sill levels. These are built by semi-skilled technicians with limited knowledge of construction as cement based construction is relatively new to Nepal. These structures are typically two to three stories.

Fig. 3 - Brick in cement masonry house

Fig. 4 – Hollow concrete block house in Nuwakot

2.1.3 Reinforced Concrete (RC) Frame with Unreinforced Masonry Infill

This is the most desired typology by most homeowners, but at the same time the most expensive of the three prevalent structural systems. This is also the technology that is most recent. Hence, although in urban municipalities some RC frame buildings are engineered, most of them are non-engineered and constructed with limited technical guidance. For example, it is common to see beams and columns with adequate main steel reinforcement but with inadequate anchorage into the concrete. Likewise, it is common to see stirrups incorrectly bent and inadequately spaced, and concrete that is not measured properly to achieve the required mix ratio. Also, the construction workers tend to use a higher water cement ratio than required for the concrete mix to make it easier to handle and place the concrete. Since the cost of the construction is high, homeowners tend to cut corners to make up for the expensive technology such as using lesser than required size and quantity of rebars, cement, etc. Since the structural performance is reliant completely on the RC system, it is crucial that the quality of concrete strength and rebar placement be correct. The masonry infills in these frames are not connected well to the frame and hence susceptible to out of plane collapse during earthquakes. These infill walls are typically 230mm thick on the outside but 100mm thick on the inside partition walls. These structures are typically two stories or higher. Higher number of stories are more common in urban areas where people have better access to resources. It is also a sign of prosperity in the rural community if one has an RC framed building.

Fig. 5 - RC frame building with brick masonry infill in Bungamati

2.2 Lessons from the 2015 Gorkha Earthquake

Mud mortar based masonry system is inherently weak and have performed poorly in past earthquakes compared to the other two systems. 95% of the fully collapsed and 68% of the partially damaged houses in the Gorkha earthquake were built using low strength masonry. Homeowners prefer to build RC frame buildings if they can afford it, but end up compromising on the quality to cut the costs. However, in order for an RC frame building to be seismic resistant, it requires a high degree of engineered detailing and a highly skilled work force to build these buildings, which is relatively expensive in urban areas and not available at all in rural and semi urban areas of Nepal.

In a place like Nepal where most of the buildings are non-engineered, there is a need for a technology that does not require a high level of engineering expertise and skilled manpower for it to be seismic resistant. One such technology that has been proven to be effective in the past earthquakes around the world is confined masonry.

3. The Case for Confined Masonry

Confined masonry construction began development in the early years of the 20th Century in Italy. Since then, confined masonry has been practiced in Latin America, the Caribbean, Mediterranean Europe, the Middle East, the Far East, and Southeast Asia. It is a common type of construction in several countries and regions where there is a high seismic hazard, including Mexico, Chile, Peru, Italy, Iran, China, and Indonesia. In some countries such as Mexico and Peru, confined masonry provisions are included in national building codes and standards. In other countries such as Indonesia and Haiti, confined masonry is commonly used for housing construction that is not governed by codes but where standards and guidelines are available for both design and construction.

Well-built confined masonry buildings have historically proven to be resilient to earthquakes, with very few collapses and in most cases with no significant damage. In the Chilean earthquakes in 1939, 1985, and 2010, the large majority of confined masonry buildings within the areas of highest ground shaking sustained little to no damage whereas the majority of unreinforced masonry buildings in the same area either partially or entirely collapsed [4]. Similar observations were made after the 2007 Pisco, Peru earthquake [5], the 2009 Padang, Indonesia earthquake [6], and others.

Confined masonry consists of masonry walls surrounded by concrete tie-beams and tie-columns. It is similar in appearance to RC frame with masonry infill construction. However, the two systems differ primarily by their construction sequence. In framed infill construction, the concrete frame is constructed first, and then the masonry infill is placed inside the frame. In confined masonry construction, the masonry wall is constructed first, and then the concrete elements are placed around the masonry.

This difference in construction sequence has a significant effect on how different the two systems perform in seismic events. The RC frame is the primary lateral force resisting element in a framed infill structure, and thus the frame must be designed and constructed to resist the lateral forces and do so in a ductile manner. This requires that the concrete elements have a large amount of reinforcing steel and a high amount of ties to confine the concrete once cracking ensues. The requirements for the concrete strength are also high. In many emerging countries, it has proven difficult to construct concrete frames in this manner due to several factors, including the limited availability of high strength concrete and reinforcing, the high cost for these materials, the high skill level required of the workers to properly construct the frames, and the limited amount of quality assurance inspections.

In a confined masonry structure, the masonry wall is the primary lateral force resisting element. These walls are typically not reinforced. However, ductility is still achieved by the confinement provided by the concrete elements. Because the concrete beams are placed onto the masonry and the concrete columns are tied into the masonry either with dowels or with keyed joints (a technique known as "toothing"), the masonry walls and the concrete elements move together. Gaps do not form between the masonry and the concrete as it does with framed infill. This allows the masonry to continue to sustain loading and absorb energy after cracking, thereby achieving ductile behavior without reinforcing in the masonry or a high amount of reinforcing in the concrete elements. The construction quality is still important. However, a higher level of quality is easier to obtain in confined masonry compared to RC framed infill since the concrete and reinforcing requirements are significantly less.

Confined masonry has many similarities to RC framed infill construction already used in Nepal. Thus, confined masonry could potentially be introduced relatively easily in Nepal as part of its earthquake reconstruction efforts. Confined masonry could address three fundamental issues related to construction in Nepal. It would be an improvement to the existing construction practices. It would address the need of the country in the reconstruction of low-rise buildings. Finally, it could elicit a positive response from the general public on the earthquake safety of masonry buildings with concrete tie-columns and tie-beams.

The photograph (Fig. 6) below shows the natural confinement of masonry with wooden tie members (a temple developed with the masonry walls combined with the tree); an example of natural blessing in the form of confined masonry.

Fig. 6 – Natural Confined Masonry

4. Current Efforts in Nepal

People in Nepal, particularly after the Gorkha Earthquake of 2015, are desperate to build houses which are safe, serviceable and sustainable. By safety they have got a notion of earthquake resistant, by serviceability they mean culturally appropriate and comfortable for homeowners, and by sustainability they mean the houses built with locally available materials, tools and skills, and affordable. In many traditional and medieval towns people in Nepal have been living in houses of low rise, low span masonry buildings in mud mortar or recently in concrete framed buildings. The damages due to Gorkha earthquake has misguided the residents to think that houses without concrete columns or beams would not survive the earthquake damages. It has been very difficult to convince homeowners that masonry houses can also survive the damages during earthquake if properly designed and constructed. On the one hand, the residents want masonry as they have been used to living in such traditional houses, on the other they also want concrete frame elements believing that they are stronger. Confined masonry houses could be the best suitable answer for them.

4.1 The Confined Masonry Initiative

To further promote confined masonry in Nepal, the Confined Masonry Initiative (CMI) has been established as a loose network of individuals and organizations that understand the potential and need for such kind of technology in reconstruction after the Gorkha Earthquake as well as to build resilient communities for future earthquakes. The initiative was formed with the objective of promoting the technology through awareness programs, engagement of stakeholders and experts both in Nepal and internationally, and developing guidelines and manuals for confined masonry construction for Nepal. To initiate this effort, a meeting of international experts and Nepalese professionals was held on January 11, 2017 during the 16th World Conference on Earthquake Engineering (16WCEE) to discuss the strategy of promoting confined masonry technology in Nepal and developing an implementation plan.

It was agreed that confined masonry technology is not only applicable to the Nepalese context of construction but also the technology provides a better and more economical solution to low rise residential buildings in urban and semi urban settings. The meeting participants decided to actively engage in promoting the technology through several means including awareness-raising among professionals, academia, industry and government institutions, professional trainings and other high level meetings. A brainstorming was done to explore options to effectively reach out at the field level so that it will be implanted during the reconstruction phase. Considering the time constraints, it was decided to take the approach of carrying out synchronized activities for technology promotion. Considering the context and resource environment of Nepal, the current guidelines of confined masonry promoted by EERI and the Confined Masonry Network need to be adapted for the Nepal context.

4.1.1 CMI Objectives

The objectives of the initiatives for promoting confined masonry are:

- To develop new guidelines and or adapt existing guidelines and manuals on confined masonry technology to make them applicable for Nepal;
- To initiate training courses and awareness programs on confined masonry;
- To ensure wider engagement of stakeholders and experts for promotion of confined masonry;
- To work closely with international experts on confined masonry so that state of art knowledge is reflected in the Nepalese guideline of confined masonry.

4.1.2 CMI Proposed Activities and Deliverables

Two ad-hoc committees on promotion of confined masonry in Nepal were set up, a national working committee and an international advisory committee. The membership of both committees was determined at the initial meeting with provision of expanding the membership as necessary to incorporate relevant stakeholder groups and experts.

The ad-hoc committees initiated dialog with the Nepalese engineering community, academia and government to come up with specific course of actions, including review and adaption of current guidelines, policy sensitization, awareness raising and capacity building. The current members of both the national working group and the international advisory committee have begun an informal review of guidelines and begun dialogue about organizing a symposium on confined masonry technology in Nepal and other relevant activities.

4.2 Design Efforts

As part of their work in the reconstruction of Nepal, Build Change developed design guidelines for a two story confined masonry prototype building using hollow concrete block masonry. This design was included in the Nepal Department of Urban Development and Building Construction (DUDBC) Design Catalogue for Reconstruction of Earthquake Resistant Houses, Volume II. This meant that the homeowners reconstructing their houses had a government endorsed option of choosing a confined masonry design, thus allowing the homeowners to apply for government reconstruction funds to construct their homes using confined masonry. Also, since this technology was new to Nepal, it was a good opportunity for the Government engineers to promote it to the communities as well.

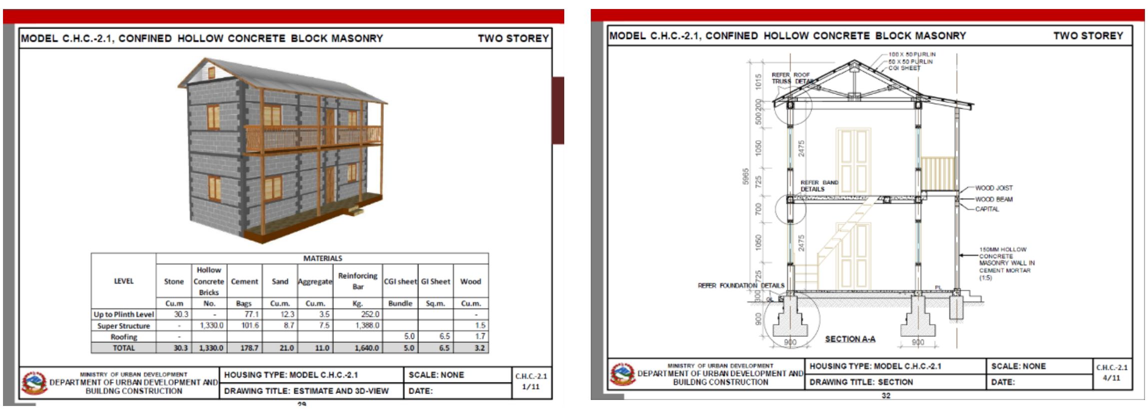

Fig. 7 - Confined hollow concrete block masonry design in DUDBC catalogue

In addition to the design catalogue, the National Reconstruction Authority has also approved a design checklist for confined masonry which can be used as a guide for confined masonry construction for homeowners. The checklist allows for the construction of confined masonry using both solid clay bricks and hollow concrete blocks. The National Reconstruction Authority engineers are authorized to approve the design of a confined masonry construction using this checklist.

5. Challenges to Introducing Confined Masonry in Nepal

5.1 Low Strength of Masonry Units

The confined masonry technology relies mostly on masonry strength to resist lateral forces; hence the quality of the masonry units is important. However, the quality of masonry units such as bricks and concrete hollow blocks are very poor in the rural and semi urban municipalities of Nepal, with lower compressive strengths than prescribed by Government standards. Concrete hollow block samples were collected from different palikas in the earthquake affected districts in Nepal. The gross compressive strength for these blocks were measured, out of which only about 20% of the blocks met the Government prescribed standard of 5MPa. The blocks that passed the standards were all from block suppliers in urban areas.

5.2 Wall Openings

Homeowners who choose to build their house with masonry walls typically want to have larger or more frequent openings in their house. Many homeowners use the ground floor of their houses for small businesses such as stores and cafes. Some homeowners want to have multiple entrances into their homes in order to accommodate extended family members or boarders living in the house. In rural villages, homes are often used to house livestock and store crops in addition to providing shelter for people. In a confined masonry design, more openings would mean a larger number of tie columns, which would increase the cost of construction of the house. In these cases, as we compare the design of an RC framed structure, which is more prevalent to a confined masonry design, the cost of the latter becomes the same or even higher with the additional tie columns. Thus there is less of an incentive for a homeowner to choose a newer confined masonry technology in place of the more prevalent RC frame technology.

5.3 The Nepal Building Code Does Not Include Provisions for Confined Masonry

There are no provisions for confined masonry in the Nepal Building Code (NBC). Thus, there is less willingness amongst practicing engineers and government officials to adopt confined masonry design as they have limited knowledge of the design process and they do not have the comfort of relying on a national building code to guide them. Since the construction practices in Nepal could be significantly different than what is the case in other countries, the direct use of codes and guidelines that were developed in other countries might not be applicable in some cases.

Another issue with the lack of confined masonry provisions in the NBC is that there is no agreed to methodology for calculating the design seismic forces for a confined masonry structure. The NBC, like other building codes, uses a ductility factor for the lateral force resisting system to calculate the design seismic forces. There is currently no ductility factor for confined masonry in the NBC. Since the ductility factors in the codes are calibrated to the seismic forces and material design provisions specific to the code, it is not possible to use the ductility factor from another code without modification. Any engineer who would design confined masonry using the NBC would need to come up with their own estimate of the ductility factor.

The Nepal Building Code includes several references to the India Standards for building construction. The India Standards have also not included provisions for confined masonry construction. However, there are currently efforts to develop such standards, using the confined masonry provisions from the Mexico building code as the basis. The pending formal adaption of confined masonry provisions into the India Standards could facilitate the adoption of confined masonry into the NBC.

5.4 Rural Construction Practices

The Gorkha earthquake affected more rural homes than urban. Hence, the need for technologies suitable for the rural context is more critical for the reconstruction effort. However, local builders in the rural areas might not have the skills required for confined masonry construction. Although builders with skills for constructing masonry walls are usually available in rural areas, the availability of builders with skills for the construction of the concrete elements might be low. In addition, concrete is usually mixed and placed manually and consolidation is usually done manually using steel bars rather than vibrators. This might lead to difficulty in achieving the required compaction in the tie columns and in the wall toothings where there might not be direct access for the compacting rod. Many builders find this tedious to carry out and chances are high that it is not done properly.

5.5 NGOs and Engineers Unfamiliar with Confined Masonry

Confined masonry is new to Nepal, so engineers tend to shy away from recommending confined masonry and instead support or recommend technologies that they are already familiar and comfortable with such as RC framed infill. This is also applicable to foreign engineers working in Nepal. Those with familiarity with multi-story reinforced concrete frame with masonry infill design could apply the same thinking to confined masonry. Thus they may be reluctant to accept confined masonry's specific concepts such as the small columns and presence of cold joints within the columns. This was the experience when confined masonry was introduced in Pakistan after the 2005 earthquake [7].

5.6 Confined Masonry Cost

For a homeowner, one of the most important criteria for choosing one technology over another is always cost. It will be natural for homeowners to compare the cost of confined masonry with that of stone or brick masonry houses and/or RC framed infill. Confined masonry is more expensive than unreinforced masonry construction. Hence, homeowners with less resources may not be able to opt for confined masonry. Whereas on the other hand, the cost of a small confined masonry unit is only about 15% lower than RC frame. The cost difference may not be high enough to tempt a homeowner with enough resources to take a risk on investing on a newer technology instead of just going for a more prevalent one.

6. Possible Solutions for Nepal

6.1 Material Supplier Training and Public Awareness Campaign to Improve Masonry Material Strengths

Both hollow concrete block and brick masonry can be used for confined masonry construction in Nepal. Whereas the use of brick masonry is more widely accepted, the use of hollow concrete blocks as structural member is more of an issue. The quality of concrete blocks that is available in the market is extremely low, and its use is confined to constructing small outdoor toilets. Three different hollow block producers, one in Kavrepalanchowk, one in Sindhupalchowk, and one in Kathmandu were interviewed to understand the block production process. It was evident that these producers had very little idea on constructing good quality blocks. For example, one of the producers had the misconception that drying the blocks out in the sun after casting would make them stronger. It is thus important to educate these construction material producers on the importance of using good quality materials, the correct process of curing and its effect on strength, and so forth.

In RC frames, the infill walls are considered as non-structural elements and hence engineers do not emphasize the need to use good quality masonry material as infill. Confined masonry looks somewhat similar to RC frames hence local engineers and homeowners might have the same misconception here. Thus, confined masonry promotion should include educating homeowners and engineers on the importance of using good quality masonry materials.

6.2 Selectively Place Wall Openings to Create Shear Walls

The design of the building should incorporate enough openings, but at the same time also be careful in considering the cost increment that comes with it. Any large opening needs to be confined with tie columns and tie beams and hence the cost of construction of a house can be high if too many openings are used. The designers should also consider strategically locating the openings to minimize the number of confining columns that are needed.

6.3 Develop Confined Masonry Guidelines Tailored Specifically for Nepal

For local design engineers as well as government engineers to have better acceptance of confined masonry technology, it is important that a confined masonry guideline for Nepal is developed and endorsed by the Nepal Government. The quickest way to do this could be adopting code provisions and guidelines from other countries that are already implementing it as much as possible. This will give engineers the basis to design a confined masonry building as well as it will have a higher likelihood of being approved by the Government if it was already available as a government approved resource. As mentioned earlier, a successful integration of confined masonry provisions into the India Standards could significantly accelerate the adoption of similar provisions into the Nepal Building Code.

Also, the guideline should include recommendations for connection detailing and member sizes that can be constructed using the standard size of materials available in the Nepal markets. For example, the tie column could be 230mm x 230 mm for a construction in brick masonry and likewise 150mm or 200mm for construction in concrete hollow block masonry. In addition, if the guidelines are prescriptive, then they are more likely to be used by engineers at all levels of experience, including relatively green engineers.

6.4 Provide Training for Local Builders & Homeowners, Emphasizing the 3 "C's": Configuration, Connections, and Construction Quality

Although the construction of confined masonry is somewhat similar to RC frame and unreinforced masonry construction, there needs to be specific trainings for confined masonry construction since features such as toothing and connection details are different than either of the other technologies.

On the job trainings on confined masonry construction was given to 118 local builders in Bhimtar village in Sangachowk Gadhi Municipality in Nepal. In the process of giving on the job trainings, 50 two roomed, one story houses were constructed. The local government engineers were also familiarized with the construction process and a brief orientation was given on confined masonry design. Using this training, in the next year more than 45 houses were constructed by the homeowners all over the municipality.

Fig. 8 - One story two room confined masonry house constructed as part of an on-the-job training

During the training, the major technology transfer challenges were in the construction of toothing and modular construction methods for constructing with hollow concrete blocks. It was realized that in place of using toothing, the use of dowels to connect tie elements and wall was found to be more appropriate in terms of ease of construction. If these small adaptations in design can be implemented, it will contribute to the wider use of this construction technology in Nepal.

6.5 Prioritize the Enhancements to Maximize the Cost Benefit and Still Provide a Higher Level of Safety

For confined masonry technology to be widely accepted in Nepal, the adaptations that need to be done include the following:

- Use of dowels to connect tie elements with walls instead of toothing.
- Position openings such that the requirement of additional tie columns are minimized and hence the subsequent cost is minimized.
- In remote areas, the tie column size needs to be wider than 150mm as it was observed that proper compaction could not be achieved by using manual methods.

7. Conclusions

One of the lessons learned from the Gorkha earthquake is that the low strength masonry buildings commonly built in Nepal are inherently weak and performed poorly in the earthquake, resulting in a large number of casualties and property loss. While RC framed infill buildings generally performed better in the Gorkha earthquake, they require a high degree of engineered detailing and a highly skilled work force to build them, which is relatively expensive in urban areas and not available at all in rural and semi urban areas of Nepal. Confined masonry has the potential to provide more resilient homes than low strength masonry and at less cost and effort than RC framed infill. A group of Nepalese design professionals and international experts agree that confined masonry technology is not only applicable to Nepalese context of construction but also that the technology provides a better and more economical solution to low rise residential buildings in urban and semi urban settings. It was also agreed that the technology must be adapted to the Nepalese context rather than imported from other countries in order for it to be successfully implemented. The challenges with doing this have been identified and efforts are underway to address them. If these challenges can be overcome, then the people of Nepal would have access to more resilient construction technology and safer homes for them to live in.

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