Experiences on Retrofitting of Low Strength Masonry Buildings by Different Retrofitting Techniques in Nepal

Hima Shrestha, Suman Pradhan, Ramesh Guragain
National Society for Earthquake Technology-Nepal (NSET)

SUMMARY
Past devastating earthquakes have proven the vulnerability of most low strength masonry buildings and the need for seismic strengthening through existing remedial measures that are inexpensive and not beyond the skills of local building industries.
This paper focuses on the collective experiences in retrofitting of school buildings and residences of low-strength masonry through different retrofitting techniques. Out of the various retrofit methods employed, wall jacketing and splint and bandage, using steel bars or galvanized wire mesh, have proven to be the most appropriate, both technically and economically viable whilst sufficiently enhancing the overall performance of the building to a level of life safety. The cost of these methods varies from $3 to $6 per square feet area of the building. This paper also includes experience of implementing an alternate retrofit approach using Polypropylene mesh (PP-band) to case masonry walls, a low-cost option for upgrading of low strength masonry buildings .

Keywords: *Non-engineered buildings, low strength masonry, retrofit techniques*

1. INTRODUCTION

Low strength load bearing masonry refers to walls constructed with non-erodible walling units such as stone, burnt clay brick, solid block, stabilized soil blocks etc., in mud mortar. Locally available masonry has been used as a construction material since ancient times and can be found all over the world, be it in residential houses, palaces, temples or important community and cultural buildings. With the advent of new construction materials and techniques, the use of these materials has substantially decreased in the last few decades, however it is still used abundantly for residential buildings in rural and remote areas of Nepal. In areas accessible by road and in the plain terrains of the south, brick is widely used, and in other northern hilly and mountainous remote areas where alternate materials are unaffordable, abundantly available stone is used. Those masonry buildings are laid in weak cement sand, mud mortar, or even dry in some cases. The quality of mortar and masonry units and the level of workmanship are poor, due to lack of awareness and economic restraints on the people. The stone masonry walls mainly consist of irregularly placed undressed stones, mostly rounded. Such buildings are of the most vulnerable categories of housing due to the nature of the material (high mass, low strength, brittle) and, in the case of low-cost housing, also the lack of proper detailing and maintenance.

The vast majority of earthquake fatalities in the last century have resulted from building failures in developing countries like Nepal. The greatest risk is by far presented to inhabitants of non-engineered low strength masonry structures as demonstrated in the earthquakes of Bam, Iran (2003), Pakistan (2005), and Pisco Peru (2007), where many of the thousands of deaths were attributable to vulnerable low strength structures. Poorly built stone and brick masonry buildings failed catastrophically under Intensities IX and VIII [NDMD, January 2006]. The weak nature of this building type was especially visible through the extensive damages in the recent 1988 Udaypur and September, 2011 Taplejung earthquakes of maximum intensity VII in eastern Nepal.

Fig 1.1Typical brick (left) and stone (right) masonry buildings in Nepal

2. TYPICAL DEFICIENCIES OF THE BUILDINGS

The damage and destruction in stone and brick masonry walls is attributed to the violation of the most basic rules of masonry construction, such as the absence of ‘through’ stones and ‘long corner’ stones in stone walls, use of mud mortar/lean cement mortar in stone or brick masonry, lack of proper connection between orthogonal walls or between the roof and walls, lack of proper workmanship and quality control, lack of cross walls and above all, the absence of earthquake resistant features, causing the building to fail in a brittle manner rather than in a ductile manner. A large number of masonry buildings suffered severe damage through past earthquakes, indicating the high level of seismic vulnerability in the region . The most common damage patterns are corner separation, formation of cracks near the corners and at openings, out-of-plane tilting of walls, collapse of roof etc. Improvement in construction practice and maintaining the integrity of the building structure, can significantly enhance the earthquake resistant performance of such buildings.

Fig 2.1 Diagonal shear failure, (left); Corner separation due to lack of integrity (right), 2005 Pakistan earthquake, Photo courtesy NSET

Fig 2.2 Failure of roof connection to wall (left); Collapse of inner wythe of stone wall due to lack of through stone (right), 18th Sept 2011Taplejung Nepal earthquake, Photo courtesy NSET

3. RETROFITTING TECHNIQUES FOR NON-ENGINEERED LOW STRENGTH MASONRY BUILDINGS IN NEPAL

Given the large number of existing masonry housing at risk in rural areas of Nepal, it is necessary to retrofit the existing dwellings rather than reconstruct. Several masonry retrofitting techniques have been developed around the world with the appropriateness of each dictated by the local topographical, economical and cultural conditions. However, dissemination of these techniques to the many communities at risk is a very challenging task [Mayorca, P. (2003)]. The methods used to effectively meet the needs of the large population in danger of non-engineered masonry collapse must be simple and inexpensive, working with the available resources and skill. Some examples of low-cost retrofitting techniques suitable for non-engineered, non-reinforced, masonry dwellings, may not necessarily save the house, however it may prevent collapse and save lives.

These techniques include enhancing the integrity of the structure by adding seismic belts, adding buttresses/cross walls, and tying roof to walls, with the aim of improving the strength and ductility of the overall system. Through studies of the damages sustained by such building types in past earthquakes, several techniques have been altered and implemented for the specific retrofit design of these buildings. Among them, the use of steel wire mesh is a popular solution. The most common methods that are implemented in Nepal for low strength masonry are described below.

The retrofitting measures mentioned in this paper are compatible with the sustainable use of the most commonly observed existing building materials in rural areas.

3.1. Wire Meshing

Unreinforced masonry buildings are brittle in nature. To ensure ductile structural behavior of such buildings, reinforcement is provided with design details specific to each building. This reinforcement consists of galvanized welded wire mesh (WWM) or TOR/MS bars that are anchored to the wall and fully encased in cement plaster or micro-concrete. Due to the low strength of masonry, full wall jacketing from both the sides is the more effective option, though the splint and bandage system also works, provided these bands are closely placed to minimize local disintegration of masonry material. The mesh on either side of the wall is connected with steel bar connectors that pass through the wall, or anchored with nails. The added concrete or plaster should be about 40 to 50 mm thick to protect the mesh from corrosion. For this purpose, either 1:3 cement-coarse sand mortar, or micro-crete i.e. concrete with small aggregates, is used. Concreting work is solely manual, without the use of shotcrete equipment, and is hence applied in two layers like plaster. If splicing is required, there should be minimum overlap of 300mm in weld mesh. If TOR/MS bars are used, adequate lap lengths must be provided. The general process in implementation of retrofitting work using steel wire mesh includes 1) Removal of plaster from walls in the proposed area for RC jacketing and Bandage/Splint 2) Rake out mortar joints to 15-25 mm depth, clean surfaces and wet with water 3) Excavate the soil for tie beam and lay the reinforcement of tie beam and wall 4) Drill in the wall and provide anchor rod to tie inner and outer steel reinforcement 5) Cast tie beam and apply concrete/plaster in two layers 6) Cure concrete.

Fig 3.1Retrofitting process using steel wire mesh

A pull down test has been carried out to assess the effectiveness of this system in the seismic upgrading of the existing buildings in Nepal. For this, two, full scale, identical brick in mud buildings were used, one in its original condition and the other with seismic retrofitting, using galvanized wire mesh. 16 gauge galvanized wire mesh @ 19 mm c/c spacing was anchored on both faces of the wall and plastered with cement sand mortar of ratio 1:3. Holes were drilled through the wall to fix the galvanized wire with cross wires, staggered @800 mm c/c.

The pulling forces vs. roof displacement, i.e. the pushover curve of the buildings, were developed from the experimental test. The loading was applied gradually to avoid dynamic amplification of stresses. Two load cells of 20 ton capacity were used to record the applied loads on each building. Three displacement transducer gauges, of 25mm measuring capacity, were used to record the small displacements induced by each increment of load. Two displacement transducer gauges of capacity 500mm were used to measure large displacements, beyond the elastic and plastic limits. Light sensors were used to capture the collapse pattern by still camera. A data logger was used to communicate the signals between the transducer and PC.

The mud mortared non-retrofitted building collapsed under a pulldown loading of 17 tons, as compared with the estimated 19.0 ton collapse loading of the numeral modelling. The numerical model indicates that the wire mesh retrofitting and plastering, increases the rigidity of the structure within the elastic limit and can resist large deformations in plastic range. The experimental results indicate an increase in rigidity of the structure within the elastic limit, with 3.5 mm displacement under 26.3 tons of loading, with no visible cracks. The building could sustain further loading but it could not be tested above 26.3 ton due to limitations of test set up. The retrofitted building sustained 1.55 times the pulldown load as compared with the similar non-retrofitted building, without any visible cracks and an estimated load carrying capacity of 2.47 times the pulldown load from numerical calculations [NSET, December, 2009]. Both analytical and experimental results concluded that this upgrading technique significantly increases the strength and stiffness of the buildings. If adequately implemented, the system will improve the performance of the buildings during future earthquakes.

Fig 3.2 Loading arrangement (left) and crack propagation (right) during pull down test of non-retrofitted building

Similar retrofitting techniques were employed in fifteen school buildings in Kathmandu Valley. Of the selected 15 school buildings, 8 were built in mud mortar, 2 in weak cement mortar, and 5 were a mix, with mud mortar in ground floor and cement mortar in first floor. Shear strength of the mortar was determined by in-situ shear test equipment for all schools. Full wall jacketing on the exterior faces of peripheral walls, and splint and bandage systems through inner wall surfaces, was opted in thirteen of the school buildings (87% of selection). Full wall jacketing on both the faces of load bearing inner and outer walls was employed for two buildings, due to inherent weaknesses. Retrofit design is shaped by the required safety levels for important structures such as school buildings, which also play a major role in post earthquake events. These two weaker buildings were of poor construction, with irregular load paths and a lack of integrity between inner and outer walls, hence the jacketing of both sides, to address the pertinent deficiency whilst ensuring minimum modification to door/window openings. This system of retrofitting was selected as the appropriate option for these buildings as the most technically and economically feasible method, aesthetically acceptable whilst enhancing the overall performance of the building, ensuring a level of life safety. More importantly, local builders and masons are easily able to carry and replicate the process independently, without any difficulty. The cost per sq ft of the plinth area was estimated at $6-7, within an affordable range for the target subjects. As more than 60% of the existing building stock in Nepal is unsafe and does not fall under the acceptable range of Life Safety [JICA, , March 2002], Nepal must resort to a seismic strengthening strategy, using appropriate measures for earthquake disaster mitigation rather than demolition and reconstruction. Unless the existing vulnerable buildings are strengthened, Nepalese citizen will be constantly facing a high risk of earthquake damage in terms of human and property loss.

Fig 3.3 Two of the school buildings before retrofitting

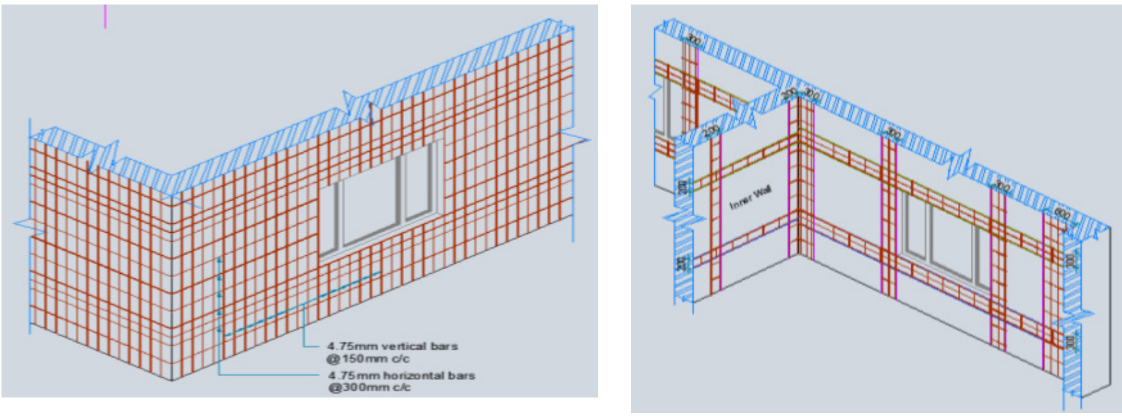

Fig 3.4 Retrofitting Option with full Jacketing in outer wall surfaces (left) and splint and bandage system in inner wall surfaces (right)

Table 3.1. Summary of Building Structural Details

School Identity	**No. of Storey**	**Average induced stress X-direction N/mm^2**	**Average induced shear stress Y-direction N/mm^2**	**Permissible value of shear strength of mortar N/mm^2**	**Retrofitting option**	**Structural Deficiency**
1. Adarsha Higher Secondary School, Bhaktapur	2	0.15	0.12	0 (Nil)	Full wall jacketing in the exterior faces of peripheral walls and splint and bandage system in inner wall surfaces	Lack of tensile strength, lack of shear strength, lack of ductility, lack of integrity between walls and between wall and roof
2. Balmiki Lower Secondary School, Bhaktapur	2	0.06	0.05	0.24		
3. Janapremi Lower Secondary School, Bhaktapur	3	0.08	0.15	0.06		
4. Kankali Secondary School, Kathmandu	2	0.10	0.11	0.24		
5. Ganesh Higher S School, Kathmandu	2	0.1	0.13	0.02		
6. Chundevi Secondary School, Kathmandu	1	0.06	0.06	0.06		
7. Mangalodaya S School, Kathmandu	2	0.16	0.22	0.04		
8. Gorakhnath Secondary School, Kirtipur	1	0.06	0.03	0.00		
9. Tripadma Vidhyashram Higher Secondary School, Lalitpur	2	0.09	0.07	0.00		
10. Janauday Lower Secondary School, Lalitpur	2	0.07	0.09	0.02		
11. Saraswoti Higher Secondary School, Lalitpur	1	0.05	0.06	0.03		
12. Balkumari Primary School, Lalitpur	2	0.07	0.07	0.04		
13. Narayani Lower Secondary School, Lalitpur	2	0.08	0.09	NA		
14. Ganesh Secondary School, Bhaktapur	2	0.09	0.10	0.04	Both side wall jacketing	Same as above in addition to significant load path problem
15. Kanya Higher Secondary School, Bhaktapur	3	0.14	0.15	0.06		

3.2 Polypropylene Meshing

Polypropylene meshing uses common polypropylene packaging straps (pp-bands) to form a mesh which is used to encase masonry walls, preventing both collapse and the escape of debris during earthquakes. PP-bands are used for packaging all over the world and are therefore cheap and readily available while the retrofitting technique itself is simple enough to be suitable for local builders. PP-meshing has been applied in Nepal, Pakistan and more recently in China.

This method is most readily applicable in terms of low-cost upgrading of traditional structures to limit damage caused by normal earthquakes and give occupants a good chance of escape in a once-in-a-lifetime large earthquake. Non-engineered masonry is widespread throughout the developing world and replacement of all such dwellings is both unfeasible and undesirable, given that they are often the embodiment of local culture and tradition. It is therefore often more feasible to consider low-cost retrofitting of such buildings. Experiments and advanced numerical simulations have shown that PP-band mesh can dramatically increase the seismic capacity of adobe/masonry houses [P. Mayorka and K Meguro, 2008]. This is mainly achieved by increasing the structural ductility and energy dissipation capacities. Under moderate ground motions, PP-band meshes provide enough seismic resistance to guaranty limited and controlled cracking of the retrofitted structures. Under extremely strong ground motions, they are expected to prevent or delay the collapse, thus, increasing the rates of survival. Experimental verification (full scale) was done in the laboratory of Tokyo University [Nesheli K et al, 2006] and also in Kathmandu, (small scale 1:6) demonstrating reliable performance improvement in the integrity of the structure and preventing material loss. This method is good for one storey buildings and can be used for a maximum of two storeys. To protect the Polypropylene from ultra violate rays, mud plaster is used on the outside, providing adequate cover to ensure the durability of the material.

Fig 3.5 Implementation of PP band method of retrofitting in Kathmandu Valley (left) and anchorage throughout the wall (right)

A pilot scheme implementing the PP-Band technology in Nepal was conducted in a rural village just outside Bhaktapur, in Nepal, by National Society for Earthquake Technology-Nepal (NSET) in collaboration with Mondialogo Engineering Award Team. The project is titled 'Improving the Structural Strength under Seismic Loading of Non- Engineered Buildings in the Himalayan Region' and outlines training courses for rural masons and public demonstrations for community members in the seismically active Himalayan region, to promote seismic resistant building and retrofitting techniques, focusing on polypropylene meshing. The main objective of the project is to disseminate and transfer the PP-band retrofitting technique to the communities who cannot afford other expensive retrofitting technology. The masons were trained through hands on implementation, found to be technically feasible and easily implemented.

In order to demonstrate the seismic response of the target building, with and without PP-band mesh retrofitting, and to compare crack patterns, failure behavior, and overall effectiveness of the retrofitting technique, a shake table test was carried out. The test verified that PP-band mesh retrofitting significantly improves the performance of the masonry building structures, maintaining the structural integrity with sufficient energy dissipation through extensively developed cracks [NSET, June 2009]. The general process of retrofitting by PP Bands includes 1) Plan modifications such as adding or removing solid walls, changing door/window openings, if required, to balance wall stiffness in both directions 2) Chipping off the wall plaster 3) Fixing of base anchor beam and tying on either side of the wall 4) Fixing of vertical PP Band starting from the outer anchor beam and ending at the inner anchor beam (this is feasible with flexible timber flooring) 5) concreting of anchor beam 6) Meshing the horizontal PP band on vertical PP band then connecting horizontal PP-Band with vertical PP-Band by Welder 7) Connecting inner and outer mesh with wires and aluminum plates 8) connecting roof elements with wall and bracing of roof 9) Mud plaster on wall to protect PP Band from ultraviolet rays.

Fig 3.6 Two identical buildings with and without retrofitting by PP Band before shake table

Fig 3.7 Shake table result' Non-retrofitted building collapse while retrofitted building is standing

4. COMPARATIVE STUDY OF DIFFERENT RETROFITTING TECHNIQUES

The following is the summary of different retrofitting techniques. Costs of retrofitting using GI welded wire mesh is less than that using steel bar mesh as the thickness of cover can be reduced, considering the wire mesh is non corrosive. However, in Nepal the availability of good quality of wire mesh is limited and sufficient cover is therefore required to protect poor quality mesh from corrosion, hence raising the costs beyond that of steel bar mesh. The cost estimated here is for retrofitting using steel bar mesh, with 50mm cover of micro concrete, and GI welded wire mesh, with 30mm cement plaster. The cost for new construction is around US$ 20 per square feet.

Table 4.1. Comparative Study of Different Retrofitting Technique

	Splint and Bandage		Jacketing		
	RCC	GI welded wire mesh	Steel bar mesh	GI welded wire mesh	PP Band
Maximum number of storey	Suitable up to 2 storey	Suitable up to 2 storey	Suitable up to 4 storey	Suitable up to 3 storey	Suitable for 1 storey
Architectural changes	Extensive	Moderate	Less	Less	Less
Intervention time	Moderate	Short/Moderate	Long	Moderate	Short
Performance objective	Life safety	Life safety	Life safety-Immediate occupancy	Life safety-Immediate occupancy	Delay collapse-Life safety
Cost per sq ft	US $ 4-6	US $ 3-5	US $ 6-8	US $ 5-7	US $ 2

5. LESSONS LEARNT AND WAY FORWARD IN RETROFITTING OF BUILDINGS IN NEPAL

Various study reports reveal that more than 60% of the building stock in Nepal is liable to suffer damaged beyond repair, resulting in high economic and human loss throughout the nation. This situation urged NSET to raise earthquake awareness in Nepal, focusing on the retrofitting of vulnerable buildings. A seismic rehabilitation program was implemented to address the vulnerability of a large proportion of buildings in Nepal, beginning with the retrofit of residential and school buildings. The methodology used thus far is technically and economically feasible and flexible enough to be adapted for other buildings in the region. NSET has since retrofitted a number of school buildings and private & organizational buildings with the intention of extending the program to the whole of Nepal in the near future.

The task of retrofitting on the national level however presents a specific challenge. The number of buildings to be considered is relatively large, more than 60% of existing building stock, whilst the number of buildings retrofitted so far is very minimal. Implementation of the retrofitting process by house owners themselves has proven unlikely with the current attitude and livelihood of the region. There are many factors behind this, of socio-economic, cultural and environmental background. The largest challenge remains in developing methodical templates and implementing retrofitting schemes, due to the poor socio-economic conditions of the nation. All considerations must include the financial limitations that the majority of house owners may encounter. Use of non-local materials for example, will have a direct impact on the expenditure and often push the economic feasibility beyond that of the house owner. This will be even more acute in villages situated away from motorable roads. Hence, extreme discretion should be exercised in the promotion of such materials. More efforts are needed to develop suitable retrofit technology for existing construction in Nepal, to improve their seismic resilience and promote the implementation of the retrofitting process in all developing regions like Nepal. It is necessary to develop a more generic approach in retrofit design/construction of buildings to reach a wider community.

The present trend of construction of vulnerable buildings without any earthquake resistant features can be overcome through capacity building, training engineers and technicians in correct building techniques. Similarly, as retrofitting is the emerging new trend in the construction industry for earthquake risk reduction, training in this field is vital for local engineers who should be encouraged to get involved.

An intensive campaign focusing on retrofitting rather than dismantling needs to be carried out as this is feasible in most of the buildings. To ensure the effectiveness of the engineers, on-site capacity building programs need be carried out in all aspects of shelter rehabilitation. This will increase their ability to guide the people. Hands-on training of masons is necessary in order to ensure correct implementation and to prevent the repetition of old mistakes and building artisans must be trained at the onset of each project. Awareness programs can be effectively used to organize community level meetings with suitably trained engineers to ensure basic understanding of the technologies developed among all of the people involved. Necessary for success is the strategic planning and integrated effort of the concerned bodies, that of the local Government, NGO's, INGO's and other related organizations and stakeholders.

ACKNOWLEDGEMENT
The project retrofitting government school buildings in Kathmandu Valley was implemented in 2011 by Department of Education, Government of Nepal with technical support from National Society for Earthquake Technology-Nepal (NSET) and financial support from Asian Development Bank. Similarly, a pilot project on implementation of PP-band technology in Nepal was conducted as a partnership between Oxford University, the Institute of Industrial Science, The University of Tokyo, the Indian Institute of Technology Bombay, Nepal

Engineering College and Khwopa Engineering College Nepal, in close collaboration with National Society for Earthquake Technology-Nepal (NSET). The same project was awarded Mondialogo Engineering Award in 2007. The authors would like to express their deep gratitude towards the project under which the tasks were successfully accomplished.

REFERENCES:

NDMD, January 2006, Guideline for Repair, restoration and retrofitting of masonry buildings in earthquake affected areas of Jammu & Kashmir, National Disaster Management Division, Ministry of Home Affairs, Government of India

Mayorca, P. (2003), Strengthening of Unreinforced Masonry Structures in Earthquake Prone Regions, Ph.D. Dissertation, The University of Tokyo, Japan.

National Society for Earthquake Technology-Nepal (NSET), December, 2009, Final report on "Pull down test of existing mud mortar masonry building", Earthquake Risk Reduction and Recovery Preparedness Program in Nepal

JICA, , March 2002, The study on Earthquake Disaster Mitigation in the Kathmandu Valley, Kingdom of Nepal, Japan International Cooperation Agency and the Ministry of Home Affairs of Nepal

P. Mayorka and K Meguro, 2008, "A step towards the formulation of a simple method to design PP-Band mesh retrofitting for Adobe/Masonry houses", 14th World Conference on Earthquake Engineering, Beijing, October 2008.

Nesheli K., Sathiparan N., Guragain R., Mayorca P., Ito F., Kagawa, H., Tsugawa, T., and Meguro K., 2006; Full-Scale Shaking Table Tests On Masonry Buildings Retrofitted By PP-Band Meshes, Proc. of the 5th International Symposium on New Technologies for Urban Safety of Megacities in Asia, Phuket,

National Society of Earthquake Technology-Nepal (NSET), June 2009, Report on "Retrofitted Building by PP-Band Mesh Technology"; Improving the Structural Strength under Seismic Loading of Non-Engineered Buildings in Himalayan Region