EARTHQUAKE HAZARD CENTRE
NEWSLETTER

Vol.18 No.3 JANUARY 2015 ISSN:1174-3646

Contents

Editorial: Reducing disaster risk with safer buildings

During 14 – 18 March the UN World Conference on Disaster Risk Reduction is to be held in Sendai, Japan. As part of the preparation for the conference a number of videos have been made to celebrate achievements during the Hyogo Framework for Action period, 2005 – 2015. Unfortunately none of this material includes information on how buildings have been made safer during this period. The draft conference programme does include a session "Standards for DRR including Building Codes" which shows awareness of the importance of the safety of buildings during natural hazards including earthquakes. However we all know what a huge gap can form between codes and their correct implementation.

From the perspective of reducing disaster risk in urban settings from earthquake and wind storms, the most important action is to improve building safety. We know that during earthquakes, buildings kill and injure people, and that badly damaged and collapsed buildings can no longer provide shelter and places for occupation.

The challenge is to build safely. This process begins with adequate building codes and standards which most countries possess. There also may be sufficient existing technical information, but all too often there is a lack of implementation. Building designs may not comply with code requirements, construction standards are low and there is no quality assurance at any stage of the design and construction phases. Safe buildings are not the outcome of inadequate processes like this.

Although there is scope for more technical information at different levels in the construction industry to achieve safer buildings, the main challenge is to change the cultures and practices of Governmental and local city council building departments. Here are some questions I would like to put to the delegates of the WCDRR in order to improve the situation:

Are there any examples of successful and unsuccessful government or local council initiatives to achieve safer buildings for their people? Please can they be widely disseminated.

How might governments and local councils change their building departments so that the safety of buildings is improved and therefore buildings represent less disaster risk?

The time has come for talking about disaster risk reduction to stop, and to do it. A vital way forward is to make whatever changes are necessary so that new construction is safer. Governmental and local city council building departments need to be part of this process.

Virtual Site Visit No. 39. Seismic retrofitting by infilling RC frames, low-rise building, Wellington.

In order to bring a four storey educational building up to the standard of the current seismic code, 11 new RC walls are being formed at ground level. The structure above this level has already been retrofitted by ductile steel cross-bracing. The new walls will act in both plan orthogonal directions and are spaced widely apart in plan to improve the torsion performance of the building.

Each new wall is formed by infilling existing RC column and beam frames with 300 mm thick RC walls. The first step is to roughen the surfaces of the columns and beams. This enables horizontal and vertical shear forces to be transferred between infills and their surrounding frame members. Then begins the drilling and grouting of horizontal and vertical starter bars (Fig. 1). In this project 16 mm diameter Grade 500 bars are epoxy grouted 350 mm into the existing members. If no reinforcing steel is encountered one hole takes about two minutes to drill. Otherwise it takes longer as a new hole is drilled nearby.

Once all the starters have been grouted, horizontal and vertical shear reinforcing is placed and tied (Fig. 2). The bar spacing is determined by the amount of shear force the new wall will resist. Note that the bending moments on the walls are resisted by compression and tension axial forces in the existing columns. Their ability to resist these forces was confirmed during the design process. The columns can be considered as flanges to the infills which themselves can be thought of as webs of the structural walls.

Door openings are necessary in some infills. In these areas additional reinforcing steel is required to ensure adequate force paths (Fig. 3). Horizontal drag bars ensure similar levels of shear stress on each side of the opening, and vertical steel trimming the opening resists secondary bending moments generated by the presence of the opening.

Once all the reinforcing has been placed and checked, formwork shutters are placed on each side of the infill. In this project self-compacting concrete is pumped into the top of the wall though several openings. It is essential that the new concrete thoroughly bonds with all vertical and horizontal surfaces, especially the surfaces of the upper beam soffits.

Figure 1. Horizontal and vertical reinforcing starter bars have been grouted into the existing beams and columns of the moment frame.

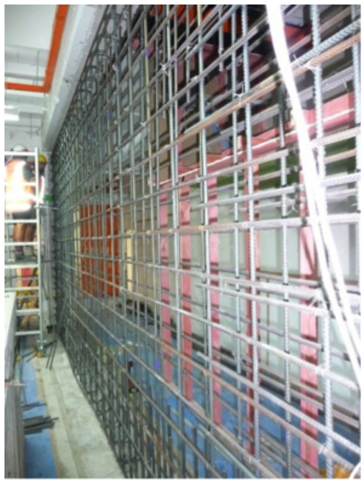

Figure 2. A completed reinforcing cage ready to be enclosed by formwork prior to casting the concrete.

Figure 3. Additional reinforcing steel is required to trim openings and to ensure adequate force paths within the infill.

A Summary of "Seismic retrofitting of non-engineered masonry in rural Nepal," by Joshua Macabuag, Ramesh Guragain and Subhamoy Bhattacharya. From *Structures and Buildings* Vol. 165, Issue SB6, 2012.

INTRODUCTION

Motivation for this study

Nearly 75% of all earthquake fatalities in the last century have resulted from building failures with a growing disparity be- tween vulnerability of those in developing and developed countries. The greatest risk is by far presented to inhabitants of non-engineered masonry structures (Fig. 4) as demonstrated in the 2003 Bam (Iran) earthquake, where many of the thousands of deaths were attributable to vulnerable adobe (mud brick) structures. Similarly vulnerable, non-engineered masonry is widespread throughout the developing world and replacement of all such dwellings is both infeasible and undesirable, given that they are often the embodiment of local culture and tradition. Therefore, it is often more feasible to consider low-cost retrofitting of such buildings. Almost 50% of the population in the developing world live in earthen dwellings yet technical research into this housing type is limited. Consider, for example, the limited volume of design guidance and supporting research in the adobe building codes of, say, Peru and New Zealand, compared with established masonry design codes such as Eurocode 6. Research is often not realised because of the difficulty of communicating developments to communities that conduct self- build without professional input. This paper, therefore, high-lights some of the key stages of developing a seismic retrofit for non-engineered dwellings, from early development to community implementation.

Figure 4. Non-engineered adobe house in Peru showing vertical crack and separation of orthogonal walls owing to out-of plane forces

Currently available retrofitting techniques for non-engineered masonry

Structural collapse under seismic loading displays many possible failure mechanisms often related to the interaction between structural components (e.g. separation of walls or floor–wall connections). When considering individual walls, earthquake loading can have components both within the plane of the wall (in-plane) and orthogonal to the plane of the wall (out- of-plane).

Methods required to meet the needs of the large populations in danger of non-engineered masonry collapse must be simple and inexpensive to match the available resources and skills. There are several examples of low-cost retrofitting techniques suitable for non-engineered, non-reinforced masonry dwellings.

This paper focuses on the technique of polypropylene (PP) meshing.

A PROPOSED RETROFITTING TECHNIQUE: POLYPROPYLENE MESHING

Procedure and previous uses

PP meshing uses common PP packaging straps (PP bands) to form a mesh, which is then used to encase masonry walls (i.e. fixing to both faces of each wall). The mesh prevents the separation of structural elements and the escape of debris, maintaining sufficient structural integrity to prevent collapse. The mesh is formed by arranging the individual bands into a grid and electrically 'welding' at intersecting points (using a plastic welder such as that shown later in Fig. 7(c)). Each wall to be retrofitted is stripped of existing render or covering, holes are drilled through the wall at regular spacing, anchor beams are installed at ground level (Fig. 7(a), see later) and a ring beam at top of wall level if lacking. The mesh is connected to both faces of the wall, fixing to the anchor beams and ring beam and passing through openings and around corners with sufficient overlap. Meshes are connected together through the wall by wires passing through the previously drilled holes. Finally the mesh is rendered over protecting the mesh from sunlight, improving fixity to the wall and making the retrofit invisible (Fig. 5).

PP bands are used as packaging the world over (e.g. tying furniture flat-packs in the UK) and are, therefore, cheap and readily available, while the retrofitting technique is simple and suitable for local builders. PP meshing has had application in Nepal, Pakistan and Kathmandu. Fig. 5 shows a retrofitted house in Pakistan following the 2005 earthquake.

(a)

(b)

Figure 5. Retrofitted house in Pakistan before and after application of covering mortar layer. Note that the mesh is also applied to the inner face of the walls, with inner and outer meshes connected with through-wall ties.

PP meshing was first formally proposed in 2000, and published in 2001.

Retrofit subsidisation programmes for low-income communities

PP band retrofitting is specifically aimed at the lowest-income communities, costing about $30 – $70/ house for materials. However, such lowest-income communities may struggle to meet basic needs and so retrofitting for earthquake safety still cannot be afforded without additional subsidy.

Considering this economical issue is, therefore, crucial to be able to disseminate the technology to the low-income communities that most need it.

Meguro Lab, Tokyo University has proposed several systems for subsidising seismic retrofits including the 'two-step incentive system' and 'new earthquake micro-insurance system'. In the proposed two-step incentive system, house owners are encouraged to retrofit their homes by receiving the necessary materials and a subsidy upon satisfactorily carrying out the work. If the retrofitted houses are damaged in an earthquake, the owners then receive twice the compensation than the house owners who did not retrofit. Table 1 shows predictions for the number of lives saved for several earthquakes, using data from dynamic experiments to calculate the percentage of building collapses that could have been prevented.

Considering the percentage of buildings potentially saved (Table 1) the reduction in expenditure of both the government and homeowners if this two-step incentive system had been in place was also estimated.

IMPLEMENTATION OF THE PROPOSED RETROFITTING TECHNIQUE

To investigate the practical issues of implementation a pilot scheme was conducted in a seismically active region of the Kathmandu Valley, Nepal.

The Himalayan region is an example of one area of constant seismic activity, high population density, and wide-spread use of non-reinforced masonry built outside of current building standards. Given the high potential for future loss of life several PP band implementation programmes have been run in this region.

	Bam earthquake (2003)		Kashmir earthquake (2005)		Java earthquake (2006)	
	Without retrofitting	Estimatedwith retrofitting	Without retrofitting	Estimatedwith retrofitting	Without retrofitting	Estimatedwith retrofitting
Totally collapsed houses	49 000	8200 (83% reduction)	203 579	5847 (97% reduction)	154 098	13 080 (92% reduction)
Partially collapsed houses			196 573	67 561 (66% reduction)	199,160	78 550 (61% reduction)
Fatalities due to total collapses	43 200	7275 (83% reduction)	58 668	1685 (97% reduction)	4559	387 (92% reduction)
Fatalities owing to partial collapses			16 367	5625 (66% reduction)	1140	450 (61% reduction)

Table 1. Reduction in casualties had the 'two-step incentive system' been adopted

Given that the dwellings most at risk are built outside of building regulations it is clear that a sustainable solution can only be achieved by raising local awareness of available methods and allowing the building owners and tradesman to themselves become the disseminators of the proposed solution.

In 2006 a public, low-tech shake-table demonstration was held in Kashmir (following the 2005 earthquake) followed by the retrofit of a full-scale building by local masons under supervision (Fig. 4). Material costs for the retrofit were around US$30 and the total installation cost was less than 5% of the total construction cost.

This section describes an implementation programme conducted in November 2008, funded by the Mondialogo Engineering Award. The programme was conducted as a partnership between Oxford University; the Institute of Industrial Science, Tokyo University; the Indian Institute of Technology, Bombay; Nepal Engineering College; Khwopa Engineering College, Nepal and the National Society of Earthquake Technology (NSET). The implementation project involved a six-day training course for local, rural masons, focusing on both earthquake construction and the pp-retrofitting technique. At the end of the course was a public low-tech shake-table demonstration of the PP band technology, inviting the community, press and key individuals and institutions.

Training programme for rural masons

The training course was coordinated by Khwopa Engineering College and engaged rural masons in several aspects of earth- quake construction: appropriate site selection, building layout and construction techniques (in masonry, timber and reinforced concrete (RC)), strengthening and repairing of existing structures and retrofitting using the PP mesh.

Many of the masons were very experienced in their trades but had never received training, or a formal education (a high level of illiteracy is another reason why a training course is required over simply producing training manuals). The aim was, therefore, to introduce small changes to current practice that can be implemented through simple rules of thumb but which significantly improve building earthquake safety. Some example features are shown in Fig. 6.

Figure 6(a) shows a load bearing masonry wall with buttressing and vertical reinforcement and with the masons preparing to add horizontal reinforcement at corners and orthogonal walls. Fig. 6(b) shows often-omitted details for local RC frames such as a double-cage for the column with a link within the beam/column joint and the beam rebar being completely contained within the column rebar and continuous through the joint.

Fig. 6(c) shows a simplified introduction to applying the PP mesh to a masonry wall. Note that the PP mesh would not usually be applied in conjunction with internal reinforcement but was applied to the reinforced masonry model purely as a simple tool for demonstrating the basics of applying the mesh. During the course it was stressed that PP retrofitting is intended for use with

(a) (b) (c)

Figure 6. Six-day training programme for rural masons, Bhaktapur, Nepal 2008

adobe where holes can be drilled through bricks as well as mortar, allowing more accurate spacing of through-wall connectors, giving a tighter mesh. The real retrofit is also continued and overlapped around corners and through openings and connected to the foundations and ring-beam (Fig. 7, see below).

Public low-tech shake table demonstration

The public demonstration was coordinated by NSET, involved two 1:6 scale masonry models (one with the PP mesh and one without) and utilised a simple spring-loaded shake-table. The demonstration was designed to allow the masons to apply what they had learnt, for the public to graphically witness the necessity to safeguard their homes and to encourage municipalities and other potential funders to adopt a retrofitting programme. The event received radio and television coverage in Nepal. Note that the simple table used is not intended to simulate accurate earthquake motion, but simply to demonstrate the effect that general ground motion can have on structures.

Outcomes of training course and demonstration

Following the training course, feedback from the masons was that they were motivated on the need for earthquake safety, very positive to be armed with simple rules-of-thumb that can be implemented easily but have an impact and keen to learn more about the PP retrofit.

The main feedback from the community after the demonstration was that community members were also motivated on the need for earthquake safety, keen to retrofit their homes but concerned over the cost of retrofitting. Municipalities and officials were keen to retrofit homes but concerned over costs.

This shows that once awareness has been raised, people are keen to safeguard their homes but subsidisation will be necessary if retrofitting is to be an option for low-income communities. It can also be seen that studies are necessary to quantitatively show municipalities and other funders the benefits of pre-emptively retrofitting rather than rebuilding post-disaster.

Real retrofit of adobe home in Nepal

The final stage of the pilot implementation programme involved retrofitting an adobe residential building in Nangkhel Village of Bhaktapur District, Nepal. The masons involved had taken part in the training course. The objectives of the real scale implementation work were:

(a) to retrofit a pilot building using the PP band retrofitting technique
(b) to observe practically the technical, economical and cultural appropriateness of the retrofitting technique under the local site conditions
(c) to give hands-on training to the local masons on the retrofitting technique and receive feedback and practical suggestions to improve the retrofitting process.

The retrofitting procedure differed from that used previously in that rather than preparing the mesh off-site and fixing to the wall, the mesh was formed directly onto the wall (Figs. 7(b) and (c)). This change was proposed by the masons themselves to improve buildability and it was suggested that in this way, it might no longer be necessary to connect the bands using the plastic welder for future projects (previously the most expensive part of the retrofit technique). This suggestion requires further investigation.

The general process of the retrofit can be seen in Fig. 7. An anchor beam was first fixed to the base of the wall inside and out; vertical PP bands were fixed between the internal and external base anchor beams; horizontal bands were then woven between and welded to the vertical bands; meshes on opposite faces of each wall were

Figure 7. Retrofit of a real adobe dwelling, Nangkhel, Nepal 2009.

connected to each other through the wall by steel wires passing through drilled holes; finally a render was applied to cover the mesh. Note that this house also required additional refurbishment work in replacing rotten floor and roof beams and infilling unnecessary openings.

The work was carried out by one NSET technician, two masons and two unskilled labourers over 4 weeks. The material costs associated with the PP retrofit came to $250. Details on full-scale retrofitting and the process described here are given in the final report of the implementation work.

The outcomes of the live retrofit were as follows:

(a) the retrofit was successfully implemented and showed that it is technically feasible to retrofit residential adobe houses using the PP band retrofitting technique
(b) by training through hands-on implementation the masons are now able to do this type of retrofitting independently
(c) the modification to the retrofitting process proposed by the masons of forming the mesh directly onto the wall proved an effective time saver; this highlights the potential benefits of developing the technique alongside those who will implement it.

SUMMARY AND RECOMMENDATIONS

This paper has introduced the technique of polypropylene meshing for preventing or prolonging the collapse of adobe buildings under strong earthquakes. Both development and implementation of this technique was considered. The main findings during the development of PP meshing are as follows:
(a) the complete PP mesh prevents loss of material and maintains wall integrity for large deformations, allowing redistribution of the load throughout the mesh and masonry
(b) PP retrofitting was shown to enhance the safety of existing single-storey masonry buildings even in worst-case earthquake scenarios such as intensity JMA 7
(c) PP band technology is cheap, readily available and easy to install, so is suitable as a retrofit for low-income communities

The main objective of the implementation work was to help disseminate safer seismic construction and retrofitting techniques to rural communities with a high proportion of non-engineered dwellings.

(a) The pilot implementation programme in Kathmandu, Nepal (training course for rural masons and public shake-table demonstration) showed that
  (i) directly engaging masons is an effective way of transferring knowledge of earthquake-safe construction directly to those responsible for the construction
  (ii) communities and officials are keen to retrofit homes but despite the low-cost, were still concerned over expense for low-income communities where supply of basic needs was more urgent.
(b) Subsidisation schemes are required to make retrofitting an attractive option for low-income households. The increased number of retrofits would in-turn lead to a substantial reduction in loss of life and cost following the next strong earthquake, for both governments and homeowners.

Director (honorary) and Editor: Andrew Charleson, ME.(Civil)(Dist), MIPENZ ,
Research Assistant: Nick Denton, BSc, BAS

Mail: Earthquake Hazard Centre, School of Architecture, PO Box 600, Wellington, New Zealand.
Location: 139 Vivian Street, Wellington.
Phone +64-4-463 6200 Fax +64-4-463-6024
Email: andrew.charleson@vuw.ac.nz